Solid Waste from Four-stroke Medium Speed Engine Power Plant Operation

Heidi Smart

The Degree Programme of Environmental Engineering

2016

BACHELOR'S THESIS

Author: Heidi Smart

Degree Programme: Environmental Engineering

Supervisors: Kaj Rintanen (Novia UAS), Piia Hannuksela and Katju Penttilä (Wärtsilä Finland Oy)

Title: Solid Waste from Power Plants Operating on Medium Speed Four-stroke Engine Technology

---

Date 20.04.2016 Number of pages 72 Appendices 10

Summary

This thesis is a study of the solid-state waste generated in power plants based on internal combustion engine (ICE) technology, supplied by the Wärtsilä Energy Solutions division. This thesis, which characterizes and quantifies the waste, was done to enhance the ability of supporting customers in issues related to social and environmental impact assessment, environmental permits, waste management planning, etc.

The Performance Standards on Environmental and Social Sustainability and the Environmental, Health and Safety guidelines of the World Bank's International Finance Corporation (IFC) act as the theoretical framework of this thesis. Organizations that are granted financing by IFC namely have to fulfil the requirements in these documents; this thesis presents what is said in the documents about solid waste.

The study was done in three parts: a calculation of engine spare part waste based on twelve engine models' maintenance schedules, a case study of auxiliary systems spare part waste from a specific power plant, and a survey regarding other types of solid waste.

Solid-state waste generated in ICE power plants consist of waste generated in offices and social facilities, oily rags, packaging material, rejected spare parts, used filters, SCR and oxidation catalyst elements, etc. The results can be used as a foundation for roughly estimating the amounts and types of solid-state waste in power plants. The exact results of the study are classified.

Language: English Key words: IFC, Performance Standards, EHS guidelines, power plant, internal combustion engine, solid waste

---

EXAMENSARBETE

Författare: Heidi Smart

Utbildningsprogram och ort: Environmental Engineering, Vasa

Handledare: Kaj Rintanen (Novia UAS), Piia Hannuksela and Katju Penttilä (Wärtsilä Finland Oy)

Titel: Solid Waste from Four-stroke Medium Speed Engine Power Plant Operation

---

Datum 20.4.2016 Sidantal 72 Bilagor 10

Abstrakt

Slutarbetet handlar om avfall i fast form som uppstår vid kraftverk som använder sig av förbränningsmotorer levererade av Wärtsiläs Energy Solutions division. Slutarbetet utreder karaktären och mängden av avfall och resultaten kommer att användas för att stöda kunder i frågor kring miljökonsekvensbedömning, miljötillstånd, planering av avfallshantering vid kraftverk, etc.

Världsbankens inernationella finansieringsbolags (IFC) ”Performance Standards on Environmental and Social Sustainability” och ”Environmental, Health and Safety guidelines” fungerar som teoretisk bas i slutarbetet. Organisationer som beviljas finansiering av IFC behöver nämligen fullfölja kraven i dessa dokument, slutarbetet presenterar vad dokumenten säger om fast avfall.

Studien gjordes i tre delar: beräkningar av avfall i form av delar som ersätts enligt tolv motorers underhållsscheman, en fallstudie av ett specifikt kraftverk och vilket reservdelsavfall dess kringutrustning gett upphov till och en enkät gällande andra typer av avfall.

Fast avfall som uppstår vid kraftverk som utnyttjar förbränningsmotorer är t.ex. avfall från kontor och sociala utrymmen, oljiga trasor, förpackningsmaterial, kasserade reservdelar, använda filter och element från SCR- och oxidationskatalyter. Resultaten kan användas som bas för att göra grova uppskattningar av avfallsmängder- och typer som uppstår vid kraftverk. Den fullständiga versionen av slutarbetet är konfidentiell.

Språk: Engelska Nyckelord: IFC, Performance Standards, EHS guidelines, power plant, internal combustion engine, solid waste

---

Table of Contents

Appendixes (only E to G included in official version)

A	Solid waste statement
B	Solid waste statement
C	Table 21
D	Tables 22-24
E	Instructions to case study power plant
F	Online survey
G	Waste survey data collection sheet
H	Case study calculations
I	Supplier contact information
J	Survey summary

Abbreviations

S&EA	Social and Environmental Impact Assessment
HFO	Heavy Fuel Oil
IFC	International Finance Corporation
EHS	Environment Health and Safety
ESP	Electrostatic Precipitator
FGD	Flue-gas Desulfurization
O&M	Operation and Maintenance
ESMS	Environmental and Social Management System
WDMS	Wärtsilä Data Management System
SAP	Systems, Applications & Products in Data Processing
GIIP	Good International Industry Practice
HHV	Higher Heating Value
EP	Equator Principles
SEMP	Social and Environmental Management Plan
EPC	Engineering, Procurement and Construction
WFI	Wärtsilä Finland
EIS	Environmental Impact Statement

1 Introduction

Activities of the human kind often give rise to different kinds of waste streams and industry is far from an exception. According to Christensen [1, pp. 10] waste can be defined as follows; *"Waste is a left-over, a redundant product or material of no or marginal value for the owner and which the owner wants to discard".* The composition of waste – the redundant products which the owner wants to dispose of – generated in industrial operations is often complex and contains fractions that require special treatment as well as valuable material, which can be recycled.

To be able to plan how to deal with the generated waste it is important to characterize it, in order to know the composition of the total waste. There are legal frameworks that regulate e.g. the handling, storing and the disposal of waste and when planning how to fulfil these requirements, knowing the waste composition is essential information. The knowledge of waste composition is also useful when planning practical procedures relating to the handling of waste, which can in turn be considered to be directly linked to cost estimations.

This is a study of solid waste (with some limitations) generated from the operation of power plants based on internal combustion engine technology. The study was made on behalf of Wärtsilä Finland Oy and the results will be used for supporting customers in issues related to waste management. The study was made under employment in the Technology and Solutions' Process and Functionality team, in close cooperation with the Environment and Performance Tools team.

1.1 Background

The Wärtsilä Energy Solutions division delivers power generation solutions, based on internal combustion engine technology worldwide, both to customers with long experience of the power generation business and to operators who are new in the field. If the customer's environmental consultant has enough experience of this type of industry they might be able to estimate the composition and quantity of the solid waste streams, but a consultant with less experience in the field cannot possess this kind of knowledge. Customers need information about waste streams e.g. when they conduct waste management planning, perform Social and Environmental Impact Assessment (S&EA) and apply for environmental permits.

So far the only document regarding waste management, which has been sent to customers upon request is the solid waste statement. There are separate statements for gas and fuel oil engines, examples of these documents are given in Appendixes A and B. These documents contain only very general information and do not say anything about the amount of waste.

Wärtsilä has not conducted any own comprehensive study on the characteristics and amounts of solid waste generated at power plants based on Wärtsilä engines during the operational phase. The knowledge is found within the company, but in order to collect it and summarize it, a cross-divisional study needs to be made. This thesis work is done in order for Wärtsilä to be able to support the customers in the planning of their waste management. The background of the thesis was defined in discussions with Katju Penttilä and Piia Hannuksela on December 3 and 7, 2015 respectively.

1.2 Purpose

The purpose of this bachelor’s thesis study is to *characterize and quantify* the waste generated at power plants utilizing Wärtsilä engine solutions. When it is known what the waste streams consist of and the extent of it, it is easier to e.g. perform waste management planning.

One partial purpose is to collect information that can be used for creating new more detailed solid waste statements, which can be sent to customers upon request. There should be separate statements for engines running on heavy fuel oil (HFO) and gas.

Proper waste treatment is beneficial to the environment and correctly planned waste management could decrease waste treatment costs. Thus another partial purpose is to do something which supports the environment and can help Wärtsilä’s customers to save on waste management costs. A third partial purpose is to give a good view of what the International Finance Corporation (IFC) requires to be known and planned regarding waste when a new project is implemented.

1.3 Limitation

The scope of this thesis is solid waste generated from power plants utilizing Wärtsilä four stroke engines running on HFO and gas. The engine types included in the study are Wärtsilä 32, 34SG, 34DF (operating on HFO), 46, 50SG and 50DF (operating on HFO) engines.

Christensen explains [1, pp. 4] that solid waste is not only waste in a solid state; Solid waste can also be liquid in the form of sludge or free chemical phase. The idea behind this is that solid waste is waste that is not water or air borne (wastewater and flue gases), i.e. solid waste does not have a transporting media like water or air that needs to be cleaned. However, this study is limited to solid waste in *solid form* (solid waste) from the operation of power plants, this includes rejected engine parts from the above mentioned engines. Spare parts from auxiliary systems are on a general level left outside the study, but a case study of a specific power plant is included.

The following fractions are left outside the study: Fly ash from electrostatic precipitators (ESP), waste related to flue gas desulphurization [(FGD), since the equipment is not that commonly used)] and solid fractions from boiler washing and cooling tower blowdown (since the particles are mixed with water). All sludge and liquid waste types are also left outside the study.

1.4 Wärtsilä

The company Wärtsilä was founded in the year 1834 and the initial activities were within the sawmill industry in Tohmajärvi in Finland [2]. Today roughly 180 years later Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets. In the year 2014 Wärtsilä had operations in more than 200 locations in close to 70 countries. The total amount of employees was approximately 17 700. Wärtsilä has three divisions: Marine Solutions, Energy Solutions and Services.

1.4.1 Marine Solutions

Marine Solutions serves customers in the marine and in the oil and gas industries by providing innovative products and solutions that are customized to meet specific customer needs. The Marine Solution’s scope of supply includes engines and generating sets, reduction gears, propulsion equipment, control systems and sealing solutions for all kinds of marine vessels and other kinds of offshore applications.

1.4.2 Energy Solutions

The Energy Solutions division supplies flexible baseload power plants, which can operate on different kinds of gaseous and liquid fuels. The product portfolio also comprises peaking, reserve and load-following power generation solutions, which can serve when there is an irregular need for power production. Power generation solutions are provided for the power generation market, to industries that require their own power generation and to the oil and gas industry. As of the year 2015 Wärtsilä has delivered 58 GW of installed power generation capacity to 175 different countries.

1.4.3 Services

Wärtsilä Marine Solutions and Energy solutions divisions provide initial installation, whereas Wärtsilä Services offers support to customers throughout the lifecycle of their installations. This includes the optimization of installation efficiency and performance. Wärtsilä Services has the largest service network in both the energy and marine industries [3].

1.4.4 Strategy

In July 2015 Wärtsilä launched an updated strategy, which emphasizes e.g. profitable growth, high quality and new innovations. The strategy also talks about meeting the needs arising from increasing environmental awareness and changing energy needs. This can be done with Wärtsilä’s energy efficient and flexible solutions. The demand for gas based technologies is also increasing and with its multiple fuel products and LNG solutions Wärtsilä is in a good position to meet these need.

The core values that shape Wärtsilä’s business are Energy, Excellence and Excitement. Fig. 1 below contains an explanation of the values and it also shows the mission and vision of the company [4].

Fig. 1. Wärtsilä's vision, mission, values and strategy [5]

Part of Wärtsilä's mission is to benefit the environment. To Wärtsilä, environmental responsibility has two dimensions: products and operations. Regarding products Wärtsilä develops and applies technologies that can reduce the environmental impact of products produced; *"We strive to develop environmentally sound products and solutions across a wide front, including technologies related to efficiency improvement, the reduction of gaseous and liquid emissions, waste reduction, noise abatement and effluent treatment".* Wärtsilä is working in a systematic manner to improve the environmental performance of its operations. Working in a systematic way means that the company activities follow certain guidelines and certified Environmental, Health and Safety management systems, which are based on ISO 14001 and OHSAS 18001 [6].

1.5 Thesis outline

In the background theory, the International Finance Corporation and its Performance Standards and Environmental, Health and Safety guidelines are introduced. These work as the foundation for the knowledge and view on waste from power plants in this thesis. Also the Equator Principles, which are based on the Performance Standards, are shortly introduced. Further the concepts social and environmental impact assessment, environmental permits and waste management are presented. When a project is implemented, these are often required and they all demand knowledge about waste generation. Finally in the background theory there is information on Wärtsilä service agreements and operation and maintenance agreements, and about waste handling in both cases.

The purpose of this study is to characterize and quantify the waste generated at power plants and this was done in three partial studies; Calculations on spare part waste generated during scheduled engine maintenance, a case study on spare part waste from the auxiliary systems, and a survey on other types of solid state waste. The procedures of the three partial studies are described in the methods chapter.

In the results chapter the identified waste types are first presented and then the outcome of the three partial studies. In the discussion the chosen methods and the results are evaluated and suggestions for development and further research are given.

2 Background theory

The standards and guidelines published by the International Finance Corporation (IFC) have been chosen as the framework – regarding the definition, characterization and management of solid waste – for this study.

Applicable regulations actually depend on in what region, country or part of the world a project is situated. However, the IFC framework can be seen as a set of minimum requirements for projects. IFC is an important authority regarding environmental, health and safety issues in projects and it was estimated that around one third of Wärtsilä projects adhere to it. This is the largest partition of projects covered by a single regulatory framework. In order to enhance the importance of waste management in projects and in order to show the instances where information on solid waste from the operational phase is required, a thorough presentation of the IFC framework documents is given in this chapter.

In Chapter 1.1 Background it is mentioned that Wärtsilä's customers need information about the types and amounts of waste when they perform S&EA, conduct waste management planning and apply for environmental permits. All these three processes are included in this theory chapter. The S&EA process is a vast and essential part of the work to be done prior to the implementation of a project and it comprises issues related to waste. To exemplify this, the theory contains a reference example; a comparison of the general S&EA process to the S&EA report of a specific power plant. The background theory also comprises chapters about Wärtsilä's proceedings regarding solid waste in case of an operation and maintenance (O&M) or service agreement.

2.1 International Finance Corporation

The International Finance Corporation is one of the most important rule setting institutions regarding the environmental matters in projects in developing countries. It is one of the five World Bank Group organizations. The other four organizations are The International Bank for Reconstruction and Development, The International Development Association, The Multilateral Investment Guarantee Agency and The International Centre for Settlement of Investment Disputes [7].

IFC is a global development institution that works towards the private sector, its purpose is to support sustainable development and growth in developing countries. The means for achieving this is to finance investments, mobilize capital in international financial markets and provide advisory services to companies and governments. IFC also supports its clients by addressing issues related to finance, infrastructure, employee skills and regulations [8]. IFC's work is guided by its Sustainability Framework which consists of four parts: The Policy on Environmental and Social Performance, the Performance Standards on Environmental and Social Sustainability (Performance Standards), the Access to Information Policy and Environmental and Social Categorization [9].

IFC's tools for safeguarding sustainable development in developing countries where projects are implemented are the Performance Standards and the Environmental, Health, and Safety (EHS) Guidelines. Organizations that are granted financing by IFC are obliged to fulfil the requirements presented in these [10]. Further there are the Equator Principles (EP) which have been developed by the Equator Principles Association and are based on the IFC Performance Standards [11].

Fig. 2 below shows the structure of what is handled in this thesis regarding IFC. The IFC Performance Standards stipulates that Social and Environmental Impact Assessment needs to be done and work as the foundation for the Equator principles. IFC has presented general and industry specific Environmental Health and Safety guidelines. This thesis focuses on the general guideline 1.6 Waste Management and the industry specific guidelines for the thermal industry.

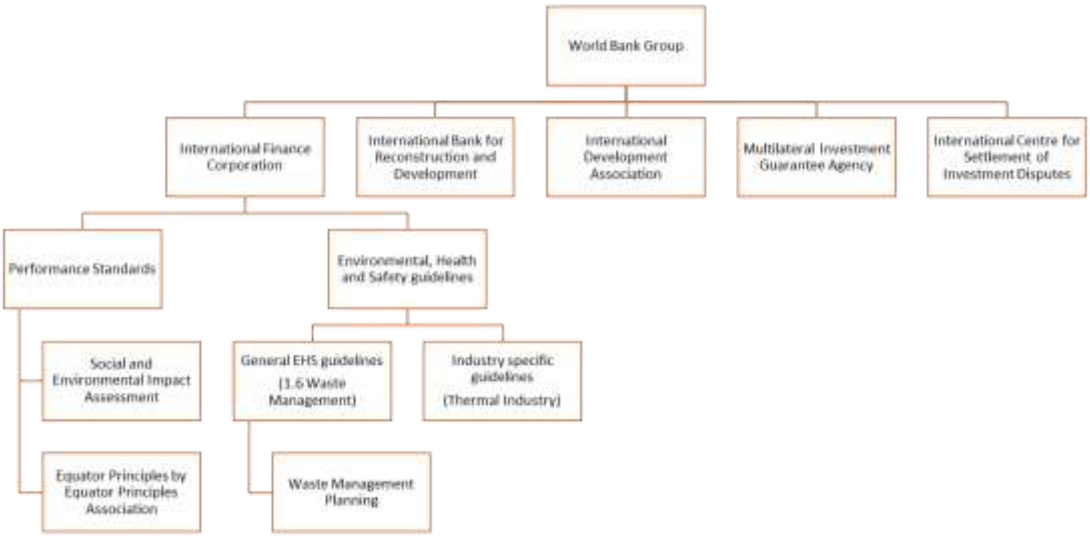


Figure 2. The topics under International Finance Corporation are handled in this thesis.

2.1.1 Performance Standards

The Performance Standards are meant for IFC clients, which is the *"party responsible for implementing and operating the project that is being financed, or the recipient of the financing, depending on the project structure and type of financing"*. The standards provide guidance on how to identify, mitigate and manage risks and impacts. The standards claim clients' commitment to do business in a sustainable and transparent way, as well as other stakeholders' engagement in sustainability. The eight Performance Standards are:

1. Assessment and Management of Environmental and Social Risks and Impacts
2. Labor and Working Conditions
3. Resource Efficiency and Pollution Prevention
4. Community Health, Safety, and Security
5. Land Acquisition and Involuntary Resettlement
6. Biodiversity Conservation and Sustainable Management of Living Natural Resources
7. Indigenous Peoples
8. Cultural Heritage

In addition to fulfilling the requirements of the Performance Standards, the clients must also accomplish what is required by other applicable laws. [10, pp. i-ii]

Performance Standard 3 Resource Efficiency and Pollution Prevention is the standard which most directly addresses waste. One of the objectives of this standard is to avoid or minimize pollution from project activities which can have negative impact on the environment and human health. Another objective is to address a more sustainable use of resources. When the client has identified the environmental and social risks and impacts of the project, it can be determined if Performance Standard 3 needs to be applied. If the standard is applicable, the means for fulfilling its requirements shall be included in the client's Environmental and Social Management System (ESMS), which is described in Performance Standard 1.

The requirements of Performance Standard 3 is that the client during the whole life-cycle of the project considers ambient conditions and applies principles and techniques suitable for meeting the objectives of the standard. The principles and techniques need to be adapted to the risks and hazards caused by the type of project in question and they need to be of good international industry practice (GIIP[1]). Another requirement is that the client refers to the EHS Guidelines or some other internationally accepted sources when resource efficiency

[1] "GIIP is defined as the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally or regionally. The outcome of such exercise should be that the project employs the most appropriate technologies in the project specific circumstances." [12, pp. 2]

and pollution prevention and control techniques – this includes waste management – are selected for the project.

Regarding waste management as part of pollution prevention, the client should avoid the generation of both hazardous and non-hazardous waste. Where generation of waste cannot be avoided it should at least be reduced. Further waste material that is still generated should be reused or recovered. If it is not possible to reuse or recover waste, it should be treated, destroyed or disposed of in an environmentally sound manner. The disposal should include appropriate control of emissions and residues resulting from processing the waste material. Generated waste which is considered hazardous according to international conventions or local legislation, should be treated in facilities that have adopted GIIP. It is the client's responsibility to make sure that third parties taking care of the client's hazardous waste are reputable and legitimate companies that are licensed by relevant government regulatory agencies. The client should also ensure that he receives documentation that the waste has reached its final destination. If the client finds out that the used contractor's disposal sites are not operated according to accepted standards, he needs to consider other safe disposal options [12, pp. 1-4].

2.1.2 Environmental, Health and Safety Guidelines

On their homepage [13] IFC presents the general EHS guidelines that should be applied to all industry sectors, as well as industry specific sector guidelines. The guidelines are technical reference documents and contain examples of GIIP, as it has been specified in IFC Performance Standard 3. The general EHS guidelines cover the following four categories:

1. *Environmental* (Sections 1.1-1.8)
2. Occupational Health and Safety (Sections 2.1-2.9)
3. Community Health and Safety (Sections 3.1-3.7)
4. Construction and Decommissioning (Sections 4.1-4.3)

The industry sector guidelines has got the following eight categories:

- Forestry
- Agribusiness/Food Production
- Chemicals
- Oil and Gas
- Infrastructure

- General Manufacturing
- Mining
- *Power (subcategory Thermal Power)*

The general EHS guidelines category *Environmental* has got the subcategory 1.6 Waste Management, which apply to all categories and sizes of projects. Under the industry specific guidelines for *power* there is the subcategory Thermal Power, which apply to large scale thermal power plants. In the industry specific guidelines for thermal power plants [14] it is mentioned that if the power plant has a smaller output than specified in the industry specific guidelines (50 MW_{th}), section 1.1 Air Emissions and Ambient Air Quality in the general EHS [15] guidelines apply. However, the latter document does not say much about waste management, only that the open burning of both hazardous and non-hazardous waste is not good practice and should be avoided [15, pp. 8]. These are the three IFC guideline documents most relevant for the topic for this study.

In general it can be said that both the general and industry specific EHS guidelines specify performance levels and measures that are normally accepted by IFC and that can be achieved at moderate costs with existing technology. If the regulations of the country where a project is implemented has more stringent requirements regarding levels and measures, these shall be implemented. If the national requirements are lower than the ones of IFC, they might be accepted in some cases, but only after a comprehensive justification has been submitted to IFC. The justification must prove that the alternative levels are still consistent with the objectives in Performance Standard 3, which was described in Chapter 2.1.1 Performance Standards [13].

General EHS guidelines – Waste Management

Section 1.6 Waste Management [16] in IFC’s general EHS guidelines applies to *“projects that generate, store, or handle any quantity of waste across a range of industry sectors”.* IFC defines waste as follows:

> “A waste is any solid, liquid, or contained gaseous material that is being discarded by disposal, recycling, burning or incineration. It can be a byproduct of a manufacturing process or an obsolete commercial product that can no longer be used for intended purpose and requires disposal.”

Apart from being solid, liquid or contained gaseous material waste can be non-hazardous or hazardous. Solid non-hazardous waste is generally any garbage or refuse, it can include waste like:

- Domestic garbage
- Inert construction or demolition materials
- Refuse like e.g. metal scrap and empty containers (which have not had hazardous content)
- Residual waste like boiler slag, clinker and fly ash (hazardous in some cases, see industry specific guidelines for thermal power plants above).

Waste is considered hazardous if it has any of the following characteristics:

- Ignitability: Can create fires under certain conditions, spontaneously combustible or flash point under 60°C. For example waste oils and used solvents.
- Corrosiveness: Acidic or basic waste ($2 \geq pH \geq 12.5$) and/or waste capable of corroding metal containers. For example battery acid.
- Reactivity: Unstable under "normal" conditions or has the ability to *"cause explosions, undergo violent reactions, generate toxic fumes, gases, or vapors or explosive mixtures when heated, compressed, or mixed with water"*. Lithium-sulfur batteries and explosives are two examples.
- Toxicity: Harmful or fatal when consumed or absorbed. For example waste containing mercury, lead, etc.
- Has other physical, chemical or biological characteristics that might cause danger to human health if the waste is not correctly managed

The IFC guidelines do not include definitions of these characteristics; the definitions of the first four characteristics are obtained from the United States Environmental Protection Agency [17].

Further according to [16] local regulations and international conventions might also define other kinds of waste as hazardous. Sludge from air pollution control facilities and other discarded solid, liquid, semisolid or contained gaseous materials resulting from industrial processes has to be evaluated in each case to determine if the material is hazardous or non-hazardous.

Like Performance Standard 3 the general EHS guidelines on waste management emphasize that the amount of waste that needs to be finally disposed should be minimized.

General Waste Management

According to [16, pp 46-48] waste should be *prevented* and therefore processes should be designed and operated in such a way that waste generation and hazards related to the waste are prevented or minimized. This can be achieved by substituting raw materials with materials with preferred features, by using materials more efficiently and by instituting good housekeeping in order to avoid material losses. Further one suggestion is to use procurement alternatives that enable the return of usable materials (e.g. containers, SCR and oxidation catalyst elements) and another suggestion as how to minimize the generation of hazardous waste is to strictly prevent the mixing of non-hazardous waste with hazardous waste.

By *recycling or reusing* waste the total amount of waste might still be significantly reduced, for this purpose recycling plans can be implemented. A recycling plan should consider evaluation of the processes that produce waste and identification of materials that could be recycled, as well as recycling of products that can be reused in the same manufacturing process or in some other activity at the industry site. It should also consider the possibility of finding nearby industrial processing operations that could recycle materials which cannot be utilized at site. A recycling plan should also establish recycling goals and formal follow up on waste generation and the rates of material that is recycled. To meet the objectives of the recycling plan the employees need to get relevant training.

If after prevention, recycling and reusing waste is still generated, it should be treated and disposed of in an appropriate way. All possible measures to avoid impacts on human health and the environment have to be taken. The chosen waste management approach has to be in line with the characteristics of the waste and with local regulations.

The EHS guidelines on waste management [16, pp. 50] also states what the monitoring of waste management should include. In the context of this study it could be mentioned that tracking on trends regarding waste types and amounts should be done, that new waste streams generated should be characterized and documented periodically and that records regarding the amount of waste and its destination should be kept.

IFC's statements regarding waste management planning practices is described in Chapter 2.4 Waste Management Planning (IFC)

<u>Hazardous Waste Management</u>

Regarding hazardous waste both the guidance on general waste management and the guidance specifically for hazardous waste in the EHS guidelines on waste management [16, pp. 48-50] apply.

The management of hazardous waste should focus on preventing any harm to health, safety and the environment. In order to manage hazardous waste correctly the potential impacts and risks associated with the material during its whole life cycle has to be understood. It is also important that the contractors hired for handling, treating and disposing the waste are licensed, professional and trustworthy. Finally it has to be ensured that the management is in compliance with relevant local and international regulations.

There are special requirements on the storage of hazardous waste since it must be ensured that the waste is not released into the environment. This includes storage in a way that prevents contact between incompatible wastes and also provides enough space for inspections. Hazardous waste should also be stored in a way that protects it from direct sunlight, wind and rain, anyhow the ventilation should be sufficient. Some waste types and quantities also require secondary containment systems in case the primary hazardous waste container should leak.

The storage of hazardous waste should be managed in a careful manner and accessible only to employees trained in handling and managing storage of hazardous waste. The area where the hazardous waste is stored must be easy to identify and should be marked on a site map. The containers should be properly labelled and information about the content should be available to all employees. Labelling is important also for both the onsite and offsite transportation of hazardous waste, for offsite transportation the hazardous waste should be accompanied with a shipping paper that describes the waste and its hazardous properties. Periodic inspections of the waste storage area should be conducted and the findings should be documented. An emergency plan on how to respond if there is accidental release of hazardous waste should be developed. Underground storage tanks and piping for hazardous waste should be avoided.

For the disposal of hazardous waste both qualified commercial and governmental waste contractors can be used. If there is no such vendor available at a reasonable distance, the facility generating waste must have the technical capability to manage the waste in such a way that it diminishes the waste’s impact on the environment. The facility must also have all permits, certifications and approvals required by government authorities. Project sponsors should consider installing equipment for onsite treatment or recycling. The final option is to construct facilities for storing the hazardous waste until some treatment option becomes available.

Also small quantities of hazardous waste need to be treated correctly according to what is described above. It is mentioned that e.g. equipment and building maintenance activities might give rise to small streams of hazardous wastes such as:

- Rags contaminated with solvents and oil, empty paint cans and chemical containers
- Used lubricating oil
- Used batteries (e.g. nickel-cadmium and lead acid)
- Lighting equipment (lamps and lamp ballasts)

Industry Specific Guidelines – Thermal Power Plants

IFC's EHS guidelines for Thermal Power Plants [14] apply to all combustion processes which utilize gaseous, liquid, solid fossil and biomass fuels to produce electrical power, mechanical power, steam, heat or any combination of these. The guidelines apply to boilers, reciprocating engines and combustion turbines in new and existing facilities that produce more than 50 Megawatt of thermal input (MW_{th}) on Higher Heating Value (HHV). All potential impacts on environment, health and safety should be considered as early as possible in the planning of a project.

The Thermal Power Plants industry-specific guidelines section 1.0 Industry-Specific Impacts and Management [14, pp. 1] provides a summary of the most significant EHS issues related to the operational phase of thermal power plants. Sub-section 1.1 Environment [14, pp. 1-14] covers e.g. air emissions, effluents (thermal discharges, liquid waste and sanitary waste water), hazardous materials and oils, and *solid wastes*.

The amount of solid waste generated directly from a thermal power plant combustion process depends largely on the ash content of the fuel. The most solid waste intensive thermal processes are the ones fired by coal and bio mass. Oil combustion waste includes bottom ash and fly ash (if equipped with particulate removal), but in diesel engine processes these are not typically generated to any significant extent. Gas-fired thermal power plant processes generate almost no solid waste, since the ash content in gas is negligible. Other (low-volume) solid wastes, but which are in liquid sludge form, that could result from a thermal power plant process focused at in this study, are cooling tower sludge, wastewater treatment sludge and water treatment sludge.

Metals are compounds of concern in waste from thermal power plant processes. Ash residues and dust removed from exhaust gases may contain considerable levels of heavy metals, as well as some organic compounds. Since ash residues are inert they are typically not classified as hazardous waste, but if it is expected that the ash residues could contain noteworthy levels of heavy metals, radioactivity or other or some other potentially hazardous materials tests should be performed at the beginning of the operational phase. The test results are used in order to classify the ash waste as hazardous or non-hazardous according to local regulations or internationally recognized standards.

Some recommended ways of preventing, minimizing and controlling the solid waste volumes from thermal power plants are also described in the industry specific guidelines [14, pp. 11-13].

2.1.3 Equator Principles

Based on the IFC Performance Standards, the Equator Principles Association [18] has developed the EP. The EP is a risk management framework for projects, it is used for identifying environmental and social risks and ways of managing them. The EP have been adopted by over 80 commercial financial institutions, which require fulfilment of the principles to grant different kinds of financial products. In practice this means that 70% of international project finance debt in the emerging markets are covered by the EP and thus indirectly by the IFC Performance Standards.

2.2 Social and Environmental Impact Assessment (IFC)

One of the objectives of Performance Standard 1 Assessment and Management of Environmental and Social Risks and Impacts [19, pp. 1-3] is *“To identify and evaluate environmental and social risks and impacts of the project”.* One part of this is performing an S&EA, the extent of the assessment varies and can be e.g. a full-scale, or a limited or focused social and environmental impact assessment. Waste generated by a project and its possible impact on the environment is one issue considered in the impact assessment. The final Environmental Impact Statement (EIS) report should clarify how the generated waste will be dealt with.

2.2.1 The S&EA Process

In the IFC Environment and Social Development Department document “A Guide to Biodiversity for the Private Sector” [20] the main elements of the full-scale the S&EA process are described. The process is summarized in the picture below:

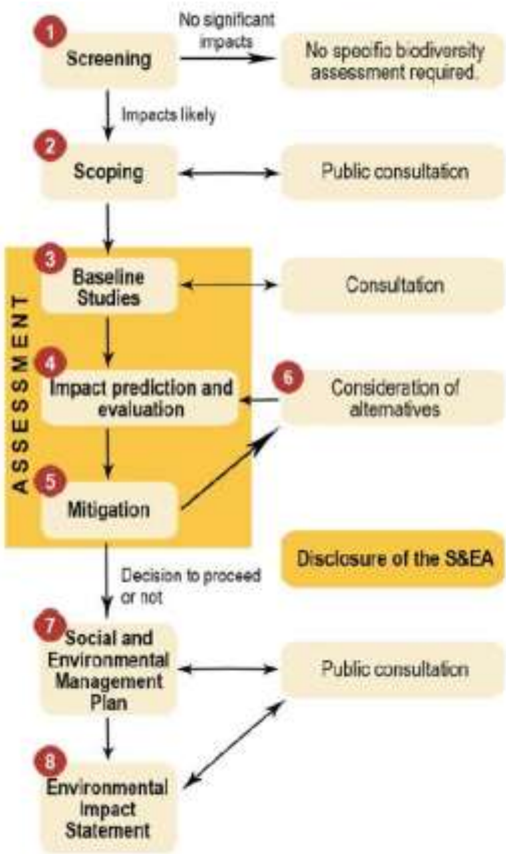


Fig. 3. Flow diagram of the Social and Environmental Impact Assessment process [20, figure].

Screening (Stage 1 in Fig. 3) is done in order to understand possible biodiversity impacts and to determine if a full-scale S&EA is needed. The location, the extent of the project and its associated facilities, as well as the impact through third party relationships are evaluated. The project surrounding is studied in order to see if there are e.g. endangered species or protected areas. The type of technology that will be used is also evaluated. Activities that might affect biodiversity are subject for more detailed analysis in the full impact assessment.

The following stage is *scoping* (2) where the focus areas of the S&EA are determined. Scoping defines data availability and suggests survey and research methodologies. During scoping government officials, conservation organizations and local communities are consulted. Feedback from these is taken into consideration when producing the final assessment plan.

Baseline studies, impact prediction and evaluation, and mitigation are part of the assessment phase of the S&EA process. *Baseline studies* (3) are made in order to investigate the present state of the environment in which the project is planned. The baseline provides reference points against which possible future impacts of the project can be compared. In the *impact prediction and evaluation* (4) the impacts of the focus areas defined in the scoping are analyzed. When the impacts are understood the significance of each impact has to be judged in order to determine if the impact is acceptable, requires mitigation or is unacceptable. Managing to identify and address significant impacts might be the key to getting the formal license to operate as well as the surrounding community's acceptance for the project. The aim of *mitigation* (5) is to eliminate or reduce negative impact on biodiversity. There are different options how this can be done, the most preferred ones are to avoid or alternatively reduce the impacts and the least favored option is to compensate for damages that are residual and cannot be avoided.

Mitigation leads to *consideration of alternatives* (6) in order to identify the least damaging option found during the mitigation. This stage can compare different project site layouts, technologies, site locations or sustainability practices of different suppliers etc.

After the assessment phase follows the creation of a *Social and Environmental Management Plan (SEMP)* (7). SEMP defines how biodiversity impacts will be managed (resources, roles and responsibilities) and how mitigation measures will be implemented. The SEMP should include information about the planned mitigation activities, by which institution it will be done, the timeline for it and a communication plan for how the progress of the SEMP will be disclosed. SEMP also works as a link between the S&EA and Social and Environmental Management System (SEMS or ESMS), which can be built up according to e.g. International Organization for Standardization (ISO) standard 14001.

Finally the physical report, the EIS (8), on the S&EA process and findings is produced. The EIS should be a comprehensive review on potential impacts and how they have been and will be mitigated in the future. The report is presented to regulatory authorities and others (including IFC) as a basis for decision making.

2.2.2 S&EA Process Example

Chapter excluded from official version of thesis.

Figure 4

2.3 Environmental Permits

The legislation regarding environmental permits vary between countries. Thus the granting institutions, the application process, the information required for the application, which kind and sizes of activities need permits and the types of environmental permits (integrated or non-integrated) should differ between countries. An example from Europe regarding waste related information asked for in environmental permit applications is given in this chapter.

The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) is an informal network built up by the environmental authorities of countries that are, have been accepted to become, and are standing for being EU member countries and Norway. IMPEL has conducted a study on waste-related conditions in environmental permits in the following countries: Austria, Belgium (Brussels Capital Region), Croatia, Cyprus, the Czech Republic, Estonia, Finland, Germany, Greece, Ireland, Slovakia, Spain, Sweden and the United Kingdom (totally 14 countries) [22, pp. 3 and 11].

The report Waste-related Conditions in Environmental Permits presents a list of information [22, pp. 32-33] that is asked for regarding waste in environmental permit applications in the studied countries. All countries require information regarding:

- Estimated total amount of generated waste
- Estimated total amount of generated hazardous waste
- Origin of waste
- Onsite storage of waste
- Data on waste recycled, recovered and disposed

Some countries also require information regarding:

- Transportation of waste (13 countries)
- European Waste Catalogue code (11 countries)
- Waste amount per production unit (9 countries)
- Internal recycling of byproducts or waste (10 countries)
- Internal energy recovery of byproducts or waste (11 countries)

It can be assumed that the information requested for in environmental permit applications in European countries is not less than in most countries in the world. Therefore this list could give good guidance regarding what waste-related issues could be included in environmental permit applications.

2.4 Waste Management Planning (IFC)

The IFC General EHS Guidelines section 1.6 Waste Management [16, pp. 47] contains information about what should be considered in waste management planning. Firstly the waste should be characterized according to:

- Composition
- Source
- Type of waste
- Generation rate
- Alternatively according to what local regulations require.

Further to effectively plan and implement waste management strategies the following things should also be done:

- A risk analysis that considers potential EHS risks during the waste cycle and the availability of facilities that can handle waste in an environmentally safe way
- Definition of opportunities for reducing, reusing and recycling waste
- Definition of how waste is safely stored onsite
- Definition of how waste is finally treated and disposed of
- During e.g. equipment modifications and process alterations new waste sources can arise and these should also be reviewed in order to identify expected waste generation and the best ways of dealing with it.

2.5 Wärtsilä Operation and Maintenance Agreements

Power plant owners can agree with Wärtsilä to have an O&M agreement for their installation. These agreements are tailor made to correspond to specific customer needs and can also include Wärtsilä personnel working continuously onsite.

2.5.1 Waste Management

If an O&M agreement has been signed it is practice that Wärtsilä is responsible for "housekeeping", which includes onsite waste management, says Benny Krohn in a discussion on December 15, 2015. This means that the Wärtsilä personnel makes sure that all waste can be collected and sorted at site according to local regulations or signed contract, whichever is more stringent. In majority of the cases Wärtsilä's contractual responsibility for the waste ends when it is collected and placed at a specified place and it is the customer's responsibility to make sure that the waste is handed over to trusted waste collecting contractors. In few cases Wärtsilä is responsible for arranging for the latter part too. The waste is always property of the power plant owner and therefore it is the owner who is accountable to the local authorities for the correct handling and possible reporting of waste streams. Because of this O&M does not have any own records of waste generated at power plant sites, unless it has been specified in the contract.

When Wärtsilä O&M performs maintenance on power plant equipment all used spare parts are washed and collected, thus no parts need to be considered hazardous waste. The used parts, which mainly consist of metal, are property of the customer and are sold for metal scrapping and recycling.

2.5.2 Engine Maintenance and Overhaul

To secure the engine performance, engine overhauls are done according to a predefined engine model specific maintenance schedule as presented e.g. in Wärtsilä 34SG Maintenance and Operation for High Performance [23]. During the overhauls different sections of the engine are maintained and some parts replaced with new ones. Between the overhauls some other scheduled maintenance work and parts replacements are also performed and if there is a specific problem unscheduled service is done.

The engine overhauls are waste generation intensive since a big mass of waste can be generated when old parts are rejected. The bulk of the waste is metal parts and wooden packaging material and a very small portion is used sealing material (mainly rubber compound) and protective plastics for the new delivered parts, says Benny Krohn on December 15, 2015. The overhaul intervals vary between engine types. On a general level it can be said that overhauls are done more frequently on engines running on HFO, since the wear on the engine is heavier when a liquid fuel is used than when a gaseous fuel is used says Mats Ohls in a discussion on December 12, 2015.

According to Olli Tarvonen on March 10, 2016 other factors that affect the degree of wear on the engines are the regularity and quality of engine maintenance. It is e.g. important that the lube oil is changed often enough in order to maintain the oil quality on a sufficient level. Also ambient conditions have an impact on the engines. Warm and moist ambient conditions give rise to condensing, which causes wear and corrosion. Dusty conditions in combination with poor suction air filtering causes dirt particles to enter the engine, which in turn causes engine wear. Therefore it is important to keep the filters clean and replace them when needed

Table 1 below gives the major overhaul intervals for the engines covered by this study. Jakob Asplund tells in communication on 8 February, 2016 that major overhauls means that required service work is done on e.g. cylinder liners, cylinder heads and pistons in order to make the engine regain its original efficiency i.e. heat rate. Between the major overhauls less time consuming overhauls are also done on other parts of the engines. Some of the overhaul intervals might be revised in the future, but these are the major overhaul intervals per February 2016 (Table 1).

Table 1. Major overhaul intervals according to engine type and fuel used.

Engine model	Fuel	Overhaul interval
Wärtsilä 32	HFO	12 000
Wärtsilä 34SG	Gas	16 000
Wärtsilä 34DF	Gas*	20 000
	HFO	12 000
Wärtsilä 46	HFO	12 000
Wärtsilä 50SG	Gas	18 000
Wärtsilä 50DF	Gas*	24 000
	HFO	12 000

*Options not touched upon in this study

2.6 Service Agreements

In case a power plant owner does not have an O&M agreement with Wärtsilä, power plant service can still be ordered for Wärtsilä, tells Ulf-Johan Björknäs in an e-mail conversation dated December 16, 2015. In these cases the Wärtsilä service personnel is still responsible for clearing the area, where the service has been carried out, from rejected spares. This is done in order to complete the work neatly and to make sure that the parts do not end up in wrong hands. The parts are demolished, sorted and disposed of at the site according to plant specific sorting rules. This is the general procedure, unless something else has been agreed upon with the customer. In case the parts are sensitive from a business point of view they can be sent to the closest Wärtsilä office or workshop.

3 Methods

Based on numerous discussions with people working in different Wärtsilä departments and with different areas of expertise, the big picture of the problem was found. This involves e.g. the possible waste streams that could be expected from a power plant based on Wärtsilä technology under operation, which technical details impact the waste streams as well as finding ways of how to collect the information. During the discussions the final frames of the study were also set, this includes which waste fractions should be focused at and which regulatory framework that was to be used.

The suggested regulatory framework was the one of IFC and the relevance of it was confirmed by calculating for how big a share of Wärtsilä projects the framework could apply. A thorough literature study of IFC documents was made in order to find out what information the organization requires to be known regarding solid waste and how waste is categorized.

The discussions and other pre-studies showed that in order to cover the major part of the estimated waste the study could be made in three parts:

3.1 Engine Spare Part Waste

The study on the amount of replaced spare parts from engines, was made based on scheduled maintenance for the twelve different engine models. The information regarding which parts are replaced when and the mass of them is found inside the company, but calculations needed to be done in order to utilize the data for the purpose of the study. By mass the major part of the spare parts is metal, thus for simplicity all engine spare parts were considered metal (See Chapter 2.5.2 Engine Maintenance and Overhaul).

The data used in the calculations was acquired from the Support and Development organization, from both the Marine and Energy Agreement teams. Of the specified engine models a random engine was chosen and the spare part weights regarding that specific engine were retrieved from SAP data (the weight data is the same data found in WDMS drawing view). Some parts' weights were not automatically acquired for the chosen engines and that data was checked manually in SAP. The engines were randomly chosen and the design stage of the engines was not considered. It is possible to create spare part weight lists only for engines that have already been built.

In some cases the turbocharger type was changed to another than the one of the randomly chosen engine. Many of the turbocharger spare parts are heavy and therefore have got a considerable impact on the results. If the calculation was done based on another turbocharger, the reason for it is described in relation to the engines in Chapter 4 Results. Table 21 in Appendix C shows some details related to this issue, as well as to engine revisions.

Appendix D is an example of the input data used; the configuration page (Table 22) shows the input used when creating the maintenance schedule, the spare part list (Table 23) shows all spare parts needed for the scheduled maintenance, and the calculation sheet (Table 24) shows how the calculation was done. The weights were picked from a list of all spare parts for the engine in question, but that list is too long to be included.

Although the weight data used was not always acquired from an engine of the latest revision the electric outputs as Megawatts electric [MW_e] used in the calculations are the outputs of the latest engine model revisions. The electric power outputs were calculated as an average of the outputs at 50 and 60 Hertz [Hz] given in the Power Plant Genset Catalogue 2015 [24]. It was discussed with Magnus Lindqvist that the weights of the engine spare parts should not differ much depending on which engine model revision is looked at. In a discussion on March 10, 2016 Olli Tarvonen supported that the components in the similar engine model revisions are almost the same and thus there is no big differences in weight.

3.2 Auxiliary Systems Spare Part Waste

The information regarding auxiliary systems maintenance and the related spare part weights is not found in an easily accessible digital form within Wärtsilä. The suppliers of this kind of equipment are in most cases non-Wärtsilä companies and the auxiliary systems are dependent on the power plant setup, which makes it difficult to conduct a general study. The study on waste in the form of rejected spare parts from auxiliary systems was therefore made in the form of a case study.

In the cases where Wärtsilä has an O&M agreement with the power plant owner, the maintenance planning for auxiliary systems is done in a data base called Maximo. Data regarding the case study power plant was retrieved from Maximo with the help of Stefan Vidgren and the data was completed with some additional spare part information from the power plant's Maintenance Manual for Auxiliaries. The weights of the spare parts are not found in Maximo and the spare part codes found in the data base are the ones of the suppliers. In SAP (Systems, Applications & Products in Data Processing) the auxiliary system spare part weights are found by a Wärtsilä material number. For this reason the data on the spare part weights was collected by contacting the suppliers. The suppliers were also asked to categorize the spare parts according to if the mass consists mainly of metal, electronic, hazardous or other (e.g. rubber, plastic, glass fiber, graphite or porcelain) material.

The wear of the auxiliary units is to some extent dependent on the power plant conditions and therefore it is not certain whether some of the maintenance and inspection works will require some new spare parts or not, i.e. the parts are replaced "as required". To get some indicating information regarding this, the contract manager of the power plant was engaged in completing the information together with the power plant staff. The written instructions on how the data was to be completed, is found in Appendix E.

3.3 Survey – Other Waste Types

To find out the magnitude of the remaining "solid-state" waste categories the electronic survey, which is given in Appendix F, was sent to power plants, which have an O&M or maintenance agreement with Wärtsilä. Additionally a data collection sheet, which is found in Appendix G, was created in order to support the data collection at the power plants. The survey also comprised some waste types which are not in a solid state and thus not included in this study, but it was decided that it is once a survey is sent out it is good to collect this data too for future purposes. Before the survey was sent out it was tested by five persons working with different tasks within Wärtsilä.

3.4 Working process

In order to maintain a structured way of working, a diary was kept on people spoken to and/or the main tasks performed during a day. During the process three meetings with Kaj Rintanen, the supervisor appointed by Novia UAS, were kept. The major part of the work was carried out at Wärtsilä and continuous feedback was received from the supervisors Piia Hannuksela and Katju Penttilä, Development Managers in the Process & Functionality and Environment & Performance Tools respectively. Feedback and good advice was also received from the General Managers of the two teams, Raymond Walsh and Eirik Linde. Totally around 580 hours inside and outside the office was put on completing the thesis.

4 Results

In this chapter the total identified waste in solid form is first described. The results of the three partial studies are given in three different subchapters. The engine spare part waste results – as calculated per the engine maintenance schedules – are described per studied engine model.

4.1 Identified Waste Types

The waste from a power plant consists of a broad range of rejected products like used spare parts, products with oil or chemical content, domestic waste, packaging material etc. As described in Chapter 3 Method, the waste was studied in three partial studies: Engine spare parts, auxiliary system spare parts and other waste fractions. Table 2 describes the waste types found in each partial study.

Table 2. Identified waste in the three partial studies.

Partial study	Waste type	Description / Example waste
Engine spare parts	Metal scrap	By mass the large majority of spare parts are metal, therefore all engine spare parts were considered metal. The rest is mainly plastic and rubber.
Auxiliary system spare parts	Metal scrap	Majority of mass made up by metal.
	Electronic	Majority of mass made up by electronics.
	Hazardous	Majority of mass made up by material considered hazardous.
	Other	Majority of mass made up by material that is not metal, electronic or hazardous. Examples: rubber, plastic, glass fiber, graphite, porcelain, etc.
Survey – Non-hazardous waste	Domestic garbage	Food scraps, small articles, plastic bottles, food packaging, etc.
	Paper	Dry and clean printing paper, magazines, newspapers, etc.
	Glass	Bottles, jars, etc.
	Waste to landfilling	Inert waste like car tires, mineral wool, PVC-plastic, etc.
	Metal scrap (excl. spare parts)	Empty containers (that have not contained hazardous material), old tools, etc.
	Used process ventilation filters	Bag filters from process ventilation. (To be handled with caution due to dust content.)
Survey – Packaging material	Cardboard	Boxes, etc.

	Plastic	Wrapping plastics, packages, etc.
	Wood	Boxes, pallets, supports, etc.
	Polystyrene	Protective sheets, etc.
	Urea packaging material	Bags and big bags.
Survey – Hazardous waste	Contaminated rags	Contaminants: Oil, solvents or other hazardous product.
	Contaminated cans, containers and drums	Contaminants: Oil, solvents, paint, etc.
	Lighting equipment and lamp ballasts	Fluorescent tubes, energy-saving lamps, etc.
	Batteries and accumulators	Nickel-cadmium, lead, etc.
	Gas filters(a	Gas filters situated on engines, gas modules and pressure reduction stations.
	SCR elements(b	Catalyst elements from selective catalytic reduction (contain vanadium pentoxide).
	Oxidation catalyst elements(c	Catalyst elements from the oxidation catalysts.
	Used charge air filters	Depending on filter type the filter elements can be contaminated with oil from the filter.
	Used fuel oil filters	Non-washable fuel oil filter elements from fuel oil filters on 32 engines.
	Ash from incinerators(d	Ash originating from incineration of e.g. oily sludge and oily rugs.
	Other hazardous waste	Mentioned by respondents: Sludge buildup from filters and separator discs, solids from charge air filters (hazardous in some cases), printer toner cartridges, oil cake from centrifugal filter.
Survey – Electronic waste	Electronic waste	Computers, printers, heaters, kitchen equipment, UPSs,etc.

[a)] In a discussion with Stefan Fältén on April 8, 2016 it was summarized that if the gas used is e.g. syngas or gas originating from oil production, oil refining or from the petrochemical industry, the filters could be contaminated with components with hazardous characteristics. Compressors in the gas network could also contaminate the gas with oil. If the gas used is clean natural gas and the gas network does not contaminate the gas with oil or other components with hazardous characteristics (as defined in Chapter 2.1.2 Environmental, Health and Safety Guidelines) the gas filters could be considered non-hazardous waste.

[b)] SCR elements contain vanadium pentoxide, which is toxic. Usually the supplier take back the used SCR elements for recycling, if not local waste treatment regulations should be followed. During usage the elements might also be contaminated by hazardous impurities (e.g. heavy metals) from e.g. the fuel and lubrication oil. [27]

[c)] In a discussion with Riitta Raudaskoski on April 11, 2016 it was concluded that oxidation catalyst elements do not contain any hazardous components, but might be contaminated with hazardous impurities in the same way as the SCR elements. The elements contain precious metals and are therefore valuable recycling goods.

[d)] According to [14] ash is inert and generally not classified as hazardous waste. However, when the material that is burnt has oil content there is the risk of hazardous compound e.g. heavy metals residue in the ashes.

4.2 Engine Spare Part Waste

In this chapter it is presented what amounts of spare part waste are generated as a result of scheduled engine maintenance on the studied engine models. The maintenance schedules were created according WFI recommendations for engines running on ≥75% base load. The calculations for the 8 000 hour periods – as per the example in Appendix D – were done according to equation (1)

$$(SPW_1 * n_1 + SPW_2 * n_2 + \cdots + SPW_x * n_x)/P_{out,el} = \frac{SPW}{P_{out,el}} \text{ [kg/MW}_\text{e}\text{]} \tag{1}$$

Where SPW is spare part weight [kg], n is number of spare parts, and $P_{out,el}$ is the electric output of the engine [MW_e]. The accumulated results were acquired by adding the results of the 8 000 hour periods.

For each engine model there is a table (Tables 3 to 14)where it is stated for which fuel usage the maintenance schedule was created, the total electric output (while fulfilling certain emission requirements) and which turbocharger was used in the calculation. In the charts the columns show the weight of exchanged spare parts (spare part waste) per Megawatt electric output [kg/MW_e] during 8 000 running hour periods up to 48 000 hours (one lifecycle). The line shows the accumulated weight of the same during 48 000 running hours. The numerical values of the waste generated during the six 8 000 hour periods and the accumulated waste during the total 48 000 hours are presented in the chart-integrated tables.

After one lifecycle the same maintenance pattern basically starts from the beginning, with the same replacement intervals for most parts. The only big difference is that pistons, cylinder linings and cylinder heads are scheduled to be replaced when their lifetime is over (e.g. at 96 000 hours for 34SG engines). These parts are *not* included in the calculations, but have to be remembered since they are heavy.

It should be kept in mind that what was calculated is the waste generation due to scheduled maintenance. Sometimes if parts are in good condition they are not replaced and sometimes service work, which is not included in the scheduled maintenance work, has to be done. In the discussion held on March 8, 2016 Magnus Lindqvist also told that when Marine and Energy Agreements make cost estimates for more comprehensive agreements they always account for unscheduled maintenance. Whether accounted for or not, unscheduled maintenance result in engine spare part waste not included in this calculation.

This chapter contains an overview of the calculation results for each of the engines. At the end of the chapter the spare part weights generated by all the twelve studied engine models are compared in a common chart.

4.2.1 Engine 12V32

Table 3 shows calculation details used for engine 12V32. The randomly chosen engine had a NA297 turbocharger manufactured by Napier. The calculation was for the sake of consistency done based on ABB's TPL65 weights, since the other studied 32 engines have TPL turbochargers (TPL65 is a possible option and was actually used when exporting the maintenance schedule).

Table 3. Calculation details for engine 12V32.

12V32		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	5.67 (900 (HFO) ppm NOx)	TPL65

The chart in Fig. 5 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during one lifecycle of a 12V32 engine is 1 047 kg/MW_e, which is equivalent to 5 938 kg per 12V32 engine.

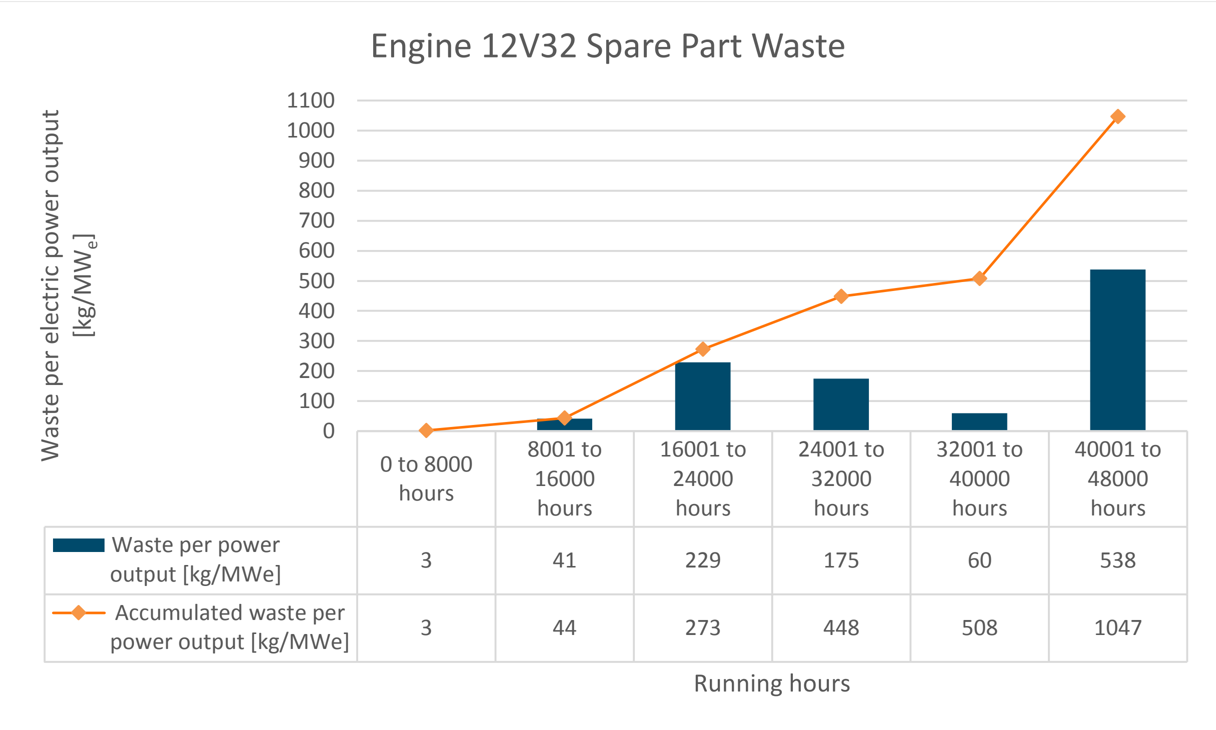


Fig. 5 Engine spare part waste generated during scheduled maintenance on an 12V32 engine.

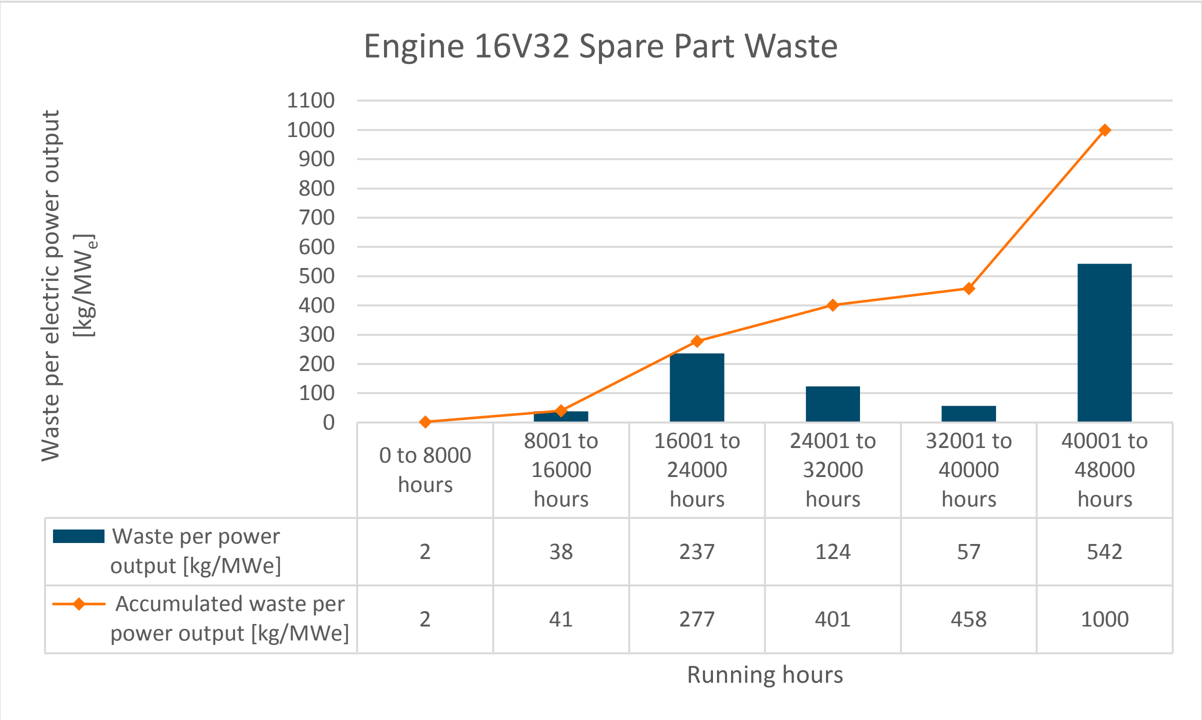
4.2.2 Engine 16V32

Table 4 shows calculation details used for engine 16V32. Turbocharger TPL67 spare part weights were used for the calculation on this engine model. The same turbo charger type was used also for the 18V32 and 20V32 engine calculations, which makes comparison between the engines straightforward. The turbocharger type is highlighted with yellow in all the three calculation detail tables.

Table 4. Calculation details for engine 16V32.

16V32		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	7.59 (900 (HFO) ppm NOx)	TPL67

The chart in Fig. 6 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during one lifecycle of a 16V32 engine is 1 000 kg/MW_e, which is 47 kg/MW_e less than by the smaller 12V32 engine. The accumulated 1 000 kg/MW_e is equivalent to 7 589 kg per 16V32 engine.



	0 to 8000 hours	8001 to 16000 hours	16001 to 24000 hours	24001 to 32000 hours	32001 to 40000 hours	40001 to 48000 hours
Waste per power output [kg/MWe]	2	38	237	124	57	542
Accumulated waste per power output [kg/MWe]	2	41	277	401	458	1000

Fig. 6. Engine spare part waste generated during scheduled maintenance on an 16V32 engine.

4.2.3 Engine 18V32

Table 5 shows calculation details used for engine 18V32. Turbocharger TPL67 spare part weights were used for the calculation on this engine model.

Table 5. Calculation details for engine 18V32.

18V32		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	8.56 (900 (HFO) ppm NOx)	**TPL67**

The chart in Fig. 7 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during one lifecycle of an 18V32 engine is 987 kg/MW_e, which is 13 kg/MW_e less than the by the smaller 16V32 engine. The accumulated 987 kg/MW_e is equivalent to 8 446 kg per 18V32 engine.

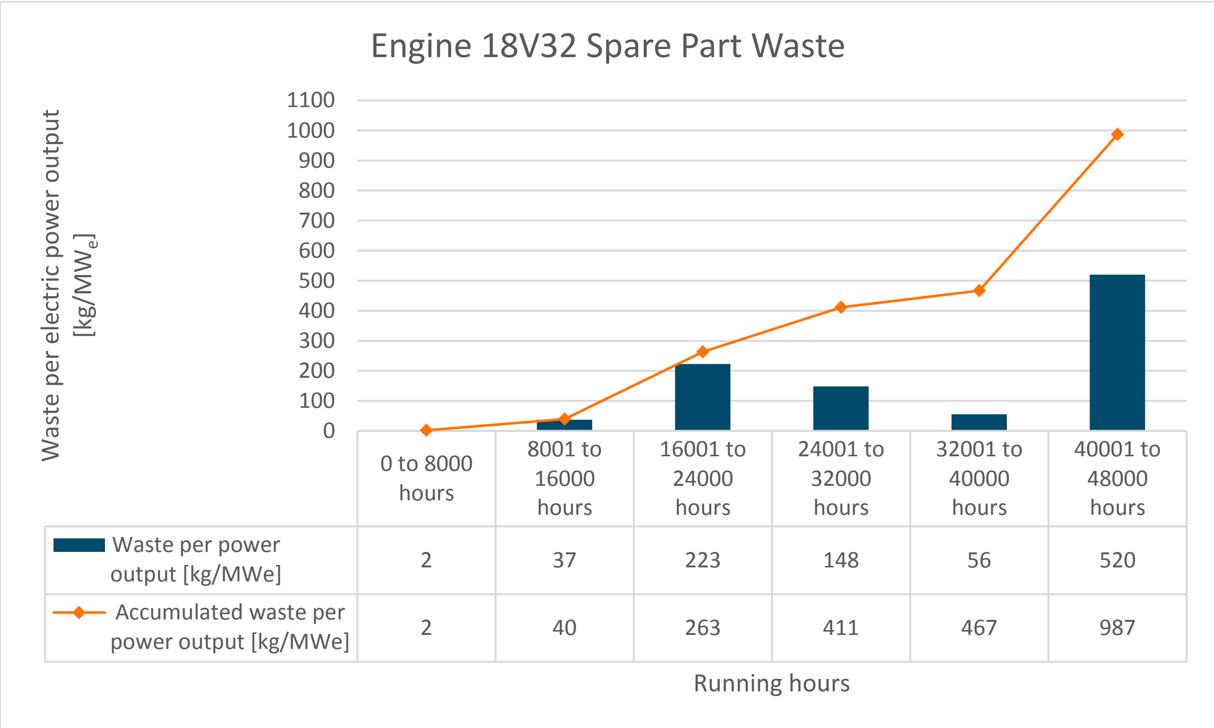


Fig. 7. Engine spare part waste generated during scheduled maintenance on an 18V32 engine.

4.2.4 Engine 20V32

Table 6 shows calculation details used for engine 20V32. Turbocharger TPL67 spare part weights were used for the calculation on this engine model.

Table 6. Calculation details for engine 20V32.

20V32		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	9.54 (900 (HFO) ppm NOx)	TPL67

The chart in Fig. 8 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during the first lifecycle of a 20V32 engine is 939 kg/MW_e, which is 48 kg/MW_e less than the by the smaller 18V32 engine. The accumulated 939 kg/MW_e is equivalent to 8 951 kg per 20V32 engine.

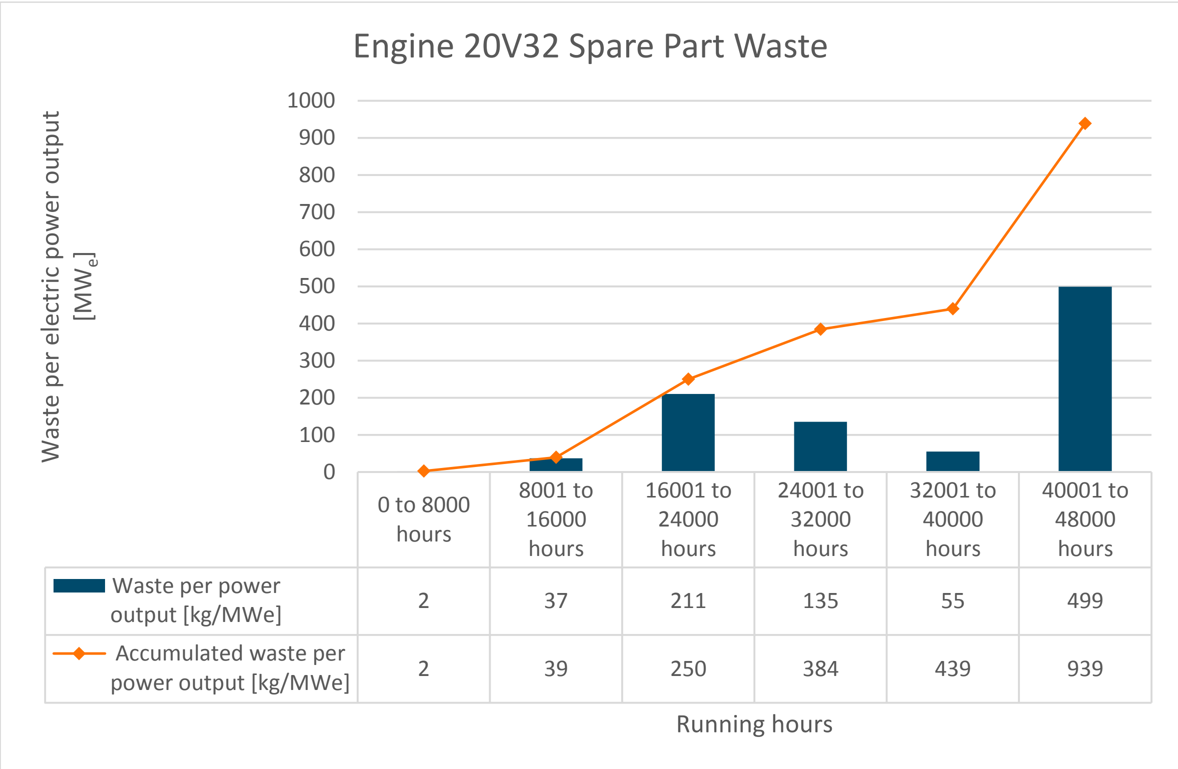


Fig. 8. Engine spare part waste generated during scheduled maintenance on an 20V32 engine.

4.2.5 Engine 16V34DF

Table 7 below shows calculation details used for engine 16V34DF. Turbocharger NA307 spare part weights were used for the calculation on this engine model. The same turbocharger spare part weights were applied to engine 16V34SG, which supports the comparison of the results of the two engine models. The turbocharger type is highlighted with blue in both engines’ calculation detail tables.

Table 7. Calculation details for engine 16V34DF.

16V34DF		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	7.59 (970 (liq.) ppm NOx CR12)	NA307

The chart in Fig. 9 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during one lifecycle of a 16V34DF engine is 809 kg/MW_e, which equals 6 137 kg per engine.

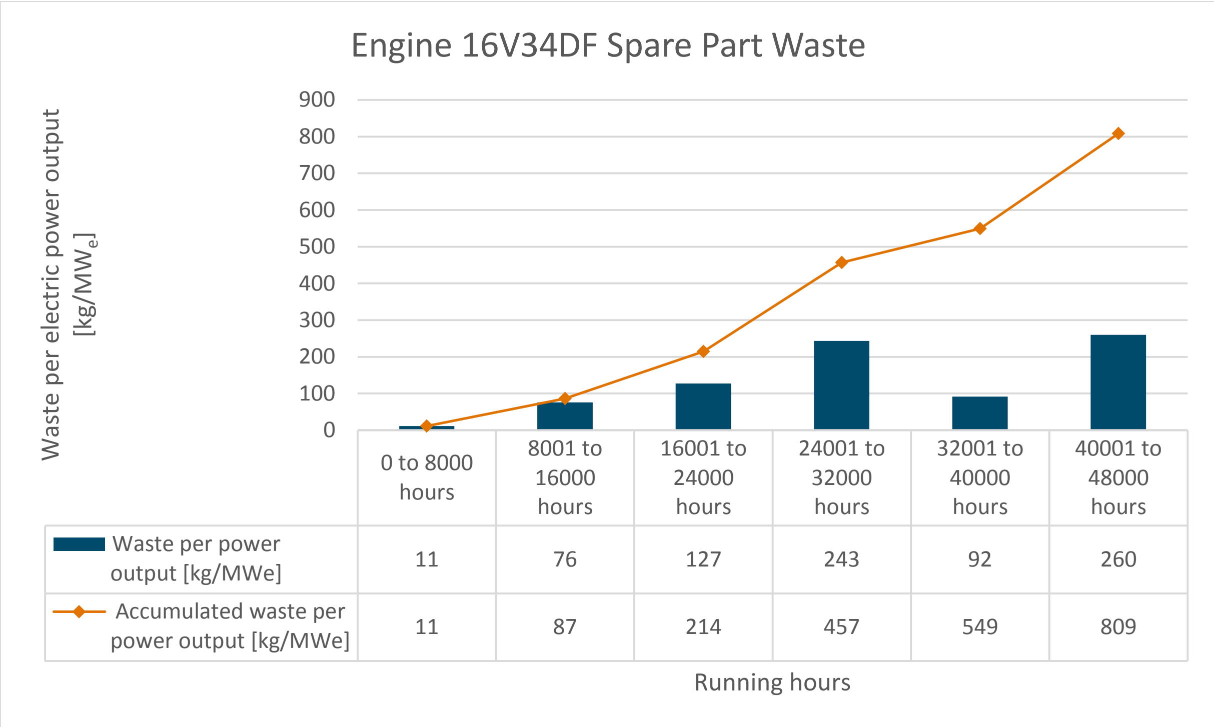


Fig. 9. Engine spare part waste generated during scheduled maintenance on an 16V34DF engine.

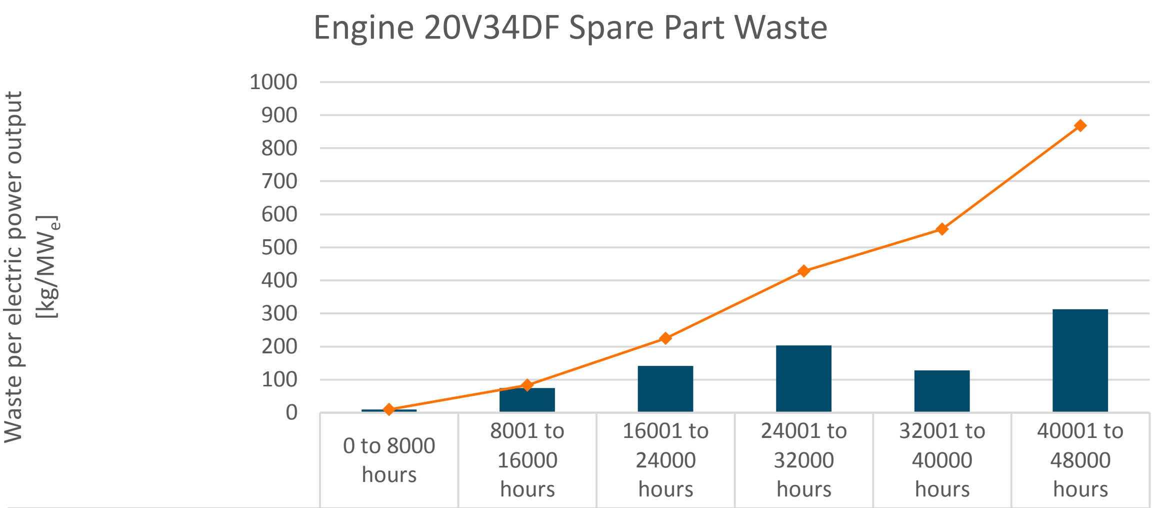
4.2.6 Engine 20V34DF

Table 8 shows calculation details used for engine 20V34DF. Turbocharger NA357 spare part weights were used for the calculation on this engine model. The same turbocharger spare part weights were applied to engine 20V34SG, which supports the comparison of the results of the two engine models. The turbocharger type is highlighted with orange in both engines' calculation detail tables.

Table 8. Calculation details for engine 20V34DF.

20V34DF		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	9.54 (970 (liq.) ppm NOx CR12)	NA357

The chart in Fig. 10 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours.



	0 to 8000 hours	8001 to 16000 hours	16001 to 24000 hours	24001 to 32000 hours	32001 to 40000 hours	40001 to 48000 hours
Waste per power output [kg/MWe]	9	74	141	203	127	312
Accumulated waste per power output [kg/MWe]	9	83	225	428	556	868

Fig. 10. Engine spare part waste generated during scheduled maintenance on an 20V34DF engine.

The spare part waste accumulated during one lifecycle of a 20V34DF engine is 868 kg/MW_e, which greater than the corresponding value, 809 kg/MW_e, of the smaller engine 16V34DF. This is because of the turbocharger parts; the parts of NA357 are heavier than the parts of NA307 and this results in at least 120 kg/MW_e more spare part waste for the 20V34DF engine. The total amount of spare part waste from a 20V34DF engine during one life cycle is 8 278 kg.

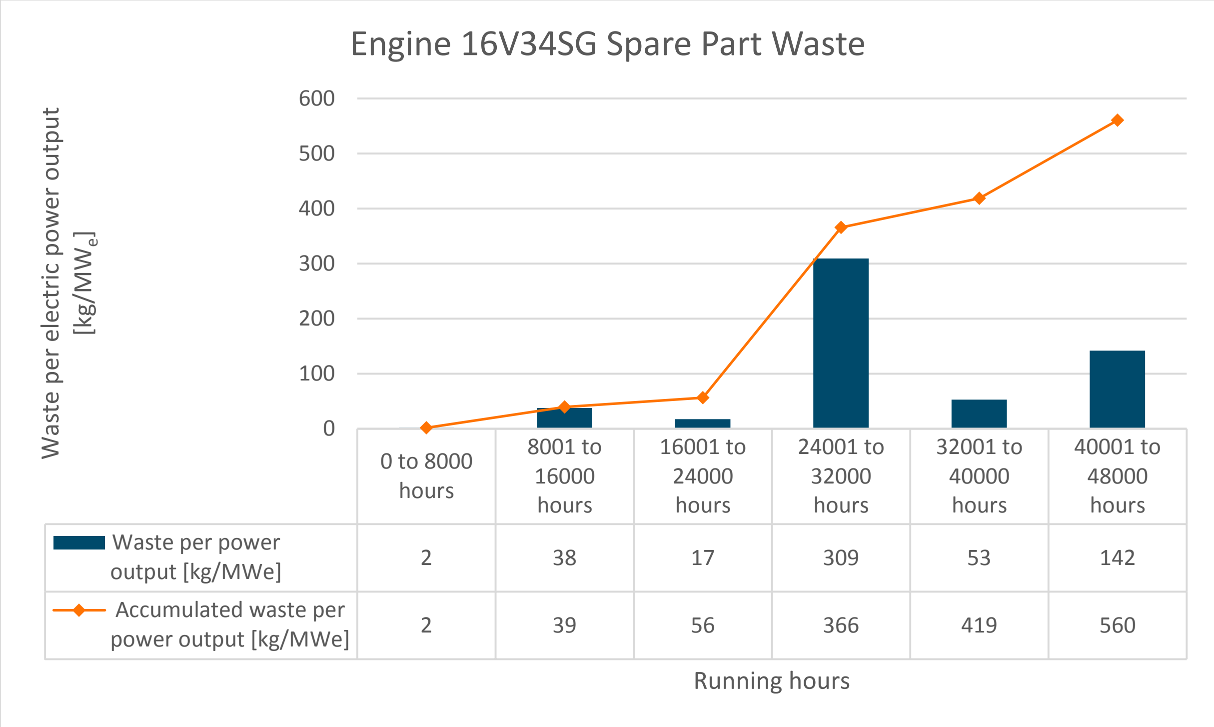
4.2.7 Engine 16V34SG

Table 9 below shows calculation details used for engine 16V34SG. Turbocharger NA307 spare part weights were used for the calculation on this engine model.

Table 9. Calculation details for engine 16V34SG.

16V34SG		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
Gas	7.59 (High MN - TA Luft)	NA307

The chart in Fig. 11 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours.



	0 to 8000 hours	8001 to 16000 hours	16001 to 24000 hours	24001 to 32000 hours	32001 to 40000 hours	40001 to 48000 hours
Waste per power output [kg/MWe]	2	38	17	309	53	142
Accumulated waste per power output [kg/MWe]	2	39	56	366	419	560

Fig. 11. Engine spare part waste generated during scheduled maintenance on an 16V34SG engine.

The spare part waste accumulated during one lifecycle of an 16V34SG engine is 560 kg/MW_e compared to 809 kg/MW_e by the 16V34DF running on HFO. On a 34SG (both 16V and 20V) engine overhaul is done every 16 000 hour and on a 34DF engine running on HFO it is done every 12 000 hour, this results in three respectively four engine overhauls during 48 000 running hours. Spare part waste of 560 kg/MW_e is equivalent to 4 252 kg per 16V34SG engine during one lifecycle.

4.2.8 Engine 20V34SG

Table 10 shows calculation details used for engine 20V34SG. Turbocharger NA357 spare part weights were used for the calculation on this engine model.

Table 10. Calculation details for engine 20V34SG.

20V34SG		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
Gas	9.54 (High MN - TA Luft)	NA357

The chart in Fig. 12 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours.

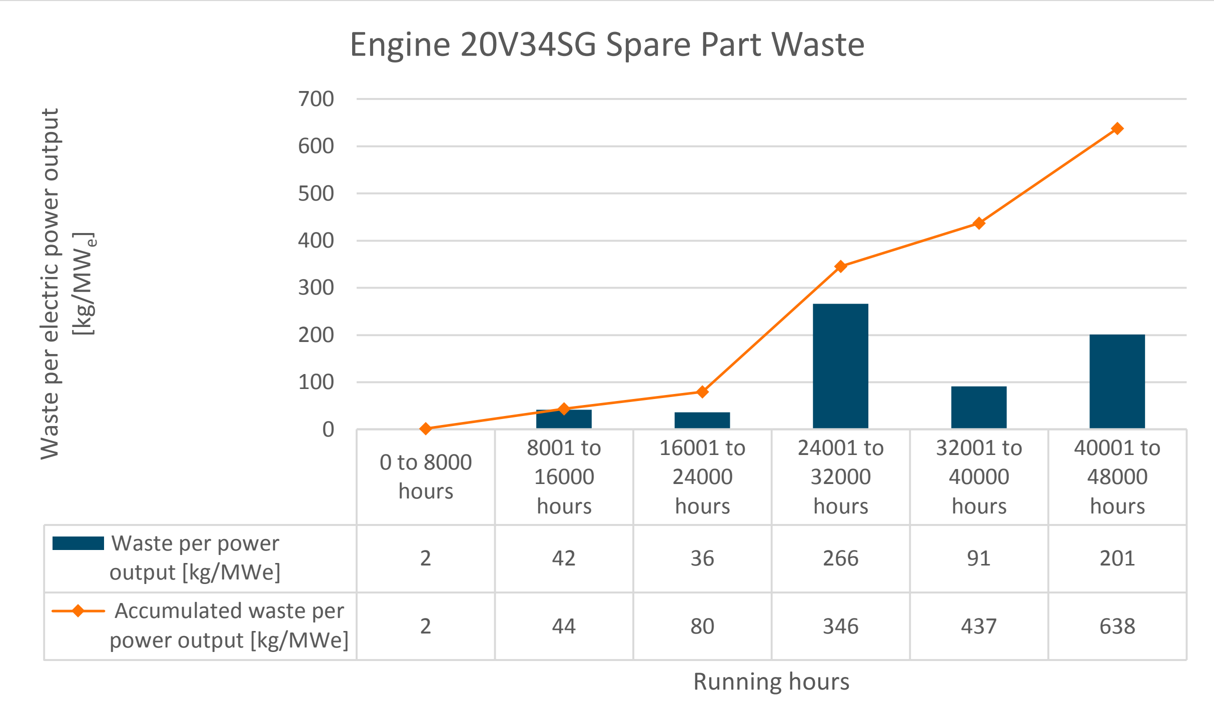


Fig. 12. Engine spare part waste generated during scheduled maintenance on an 20V34SG engine.

The spare part waste accumulated during a lifecycle of a 20V34SG engine is 638 kg/MW_e, which greater than the corresponding value, 560 kg/MW_e, of the smaller engine 16V34SG. The reason for this is – like in the 34DF case – that the weight of the turbocharger parts of NA357 are heavier than the ones of NA307. This results in at least 120 kg/MW_e more spare part waste for the 20V3SG engine. The total amount of spare part waste from a 20V34SG engine during one life cycle is 6 085 kg.

4.2.9 Engine 18V50SG

Table 11 shows calculation details used for engine 18V50SG. Turbocharger TPL76 spare part weights were used for the calculation on this engine model. The same turbocharger was used for the calculations on the 18V50DF and 18V46 engines. The turbocharger type is highlighted with green in the calculation detail tables of the engines.

Table 11. Calculation details for engine 18V50SG.

18V50SG		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
Gas	18.54 (High MN - TA Luft)	TPL76

The chart in Fig. 13 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during a lifecycle of an 18V50SG engine is 686 kg/MW_e. The total amount of spare part waste from an 18V50SG engine during one life cycle is 12 719 kg.

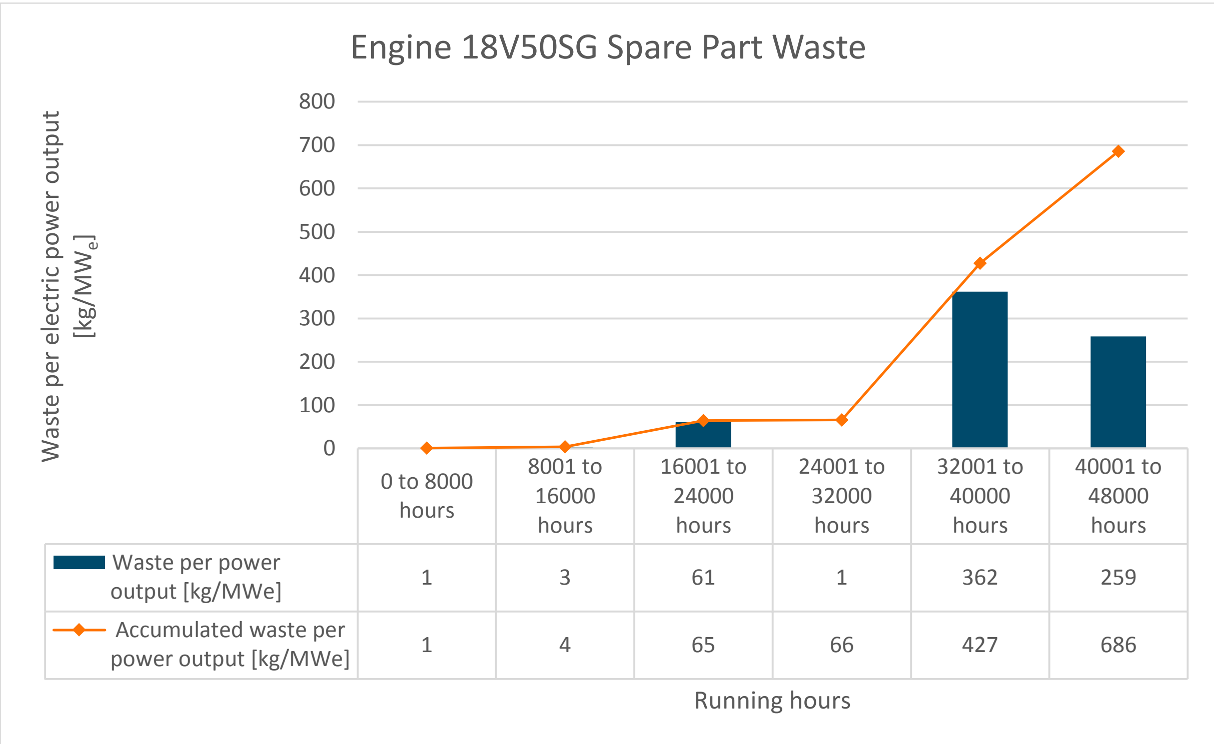


Fig. 13. Engine spare part waste generated during scheduled maintenance on an 18V50SG engine.

For the 50 SG and DF engines it is by default calculated (by the Service Calculation Office) that the charge air coolers are replaced at 54 000 hours intervals and then the first occurrence is outside 48 000 hours. For the other engines the charge air coolers are scheduled to be replaced within the period of 48 000 running hours. A charge air cooler is however, not actually replaced until deemed necessary based on performance or condition, which could be later than its expected lifetime. To make the comparison between all the twelve engines more fair, the charge air cooler replacement for the 50 SG and DF engines was added at 36 000 hours. The charge air coolers are heavy and thus have significant impact on the calculations. Including the charge air coolers for the 50 SG and DF engines was suggested by Magnus Lindqvist, who provided the engine spare part weight data.

4.2.10 Engine 18V50DF

Table 12 shows calculation details used for engine 18V50DF. Turbocharger TPL76 spare part weights were used for the calculation on this engine model.

Table 12. Calculation details for engine 18V50SG.

18V50DF		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO	16.86 (970 (liq.) ppm NOx CR12)	TPL76

The chart in Fig. 14 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours.

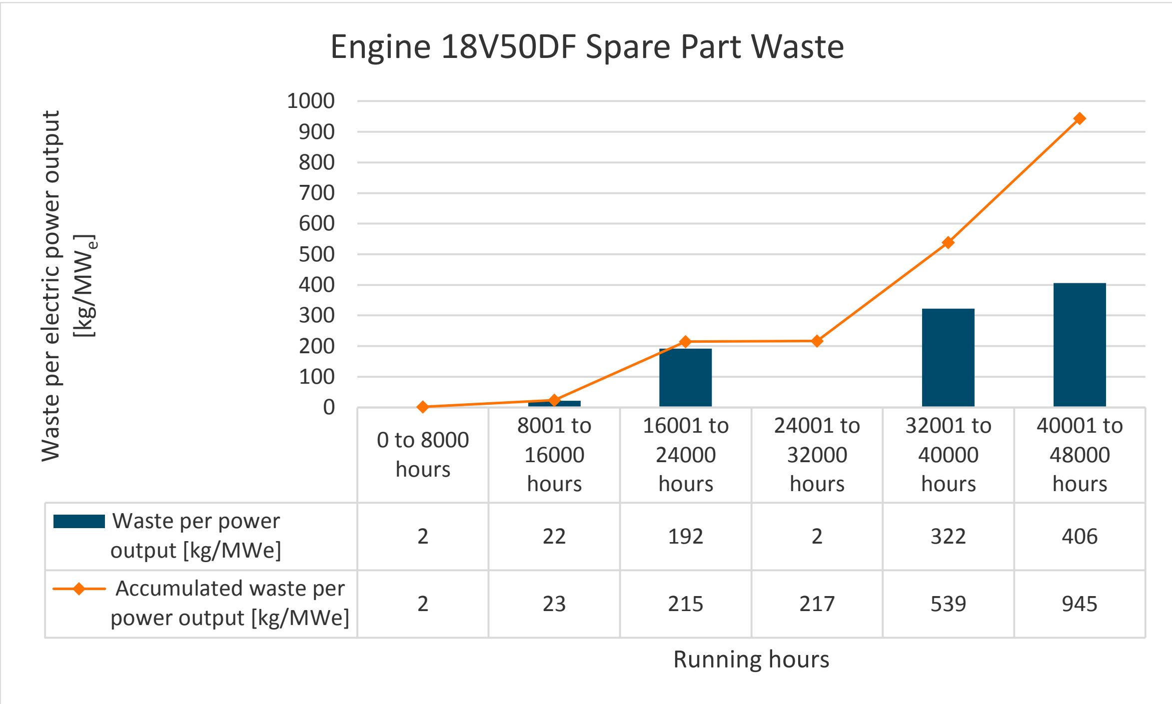


Fig. 14. Spare part waste generated during scheduled maintenance on an 18V50DF engine.

The spare part waste accumulated during a lifecycle of an 18V50DF engine is 945 kg/MW_e. This is more than for the 18V50SG engine, whose corresponding value is 686 kg/MW_e. The difference is explained by that the 50SG engine has a higher electrical output than the 50DF engine (18.54 MW_e compared to 16.86 MW_e) and that the engines are overhauled every 18 000 and 12 000 hour respectively. The total amount of spare part waste from an 18V50DF engine during one life cycle is 15 922 kg.

4.2.11 Engine 12V46

Table 13 shows calculation details used for engine 12V46. The randomly chosen engine had a TPL71 turbocharger, but the calculation was done based on TPL73 weights (TPL73 is a possible option and was used when exporting the maintenance schedule).

Table 13. Calculation details for engine 12V46.

12V46		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	11.38 (900 ppm NOx)	TPL73

The chart in Fig. 15 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours. The spare part waste accumulated during a lifecycle of a 12V46 engine is 849 kg/MW_e. The total amount of spare part waste from a 12V46 engine during one life cycle is 9 670 kg.

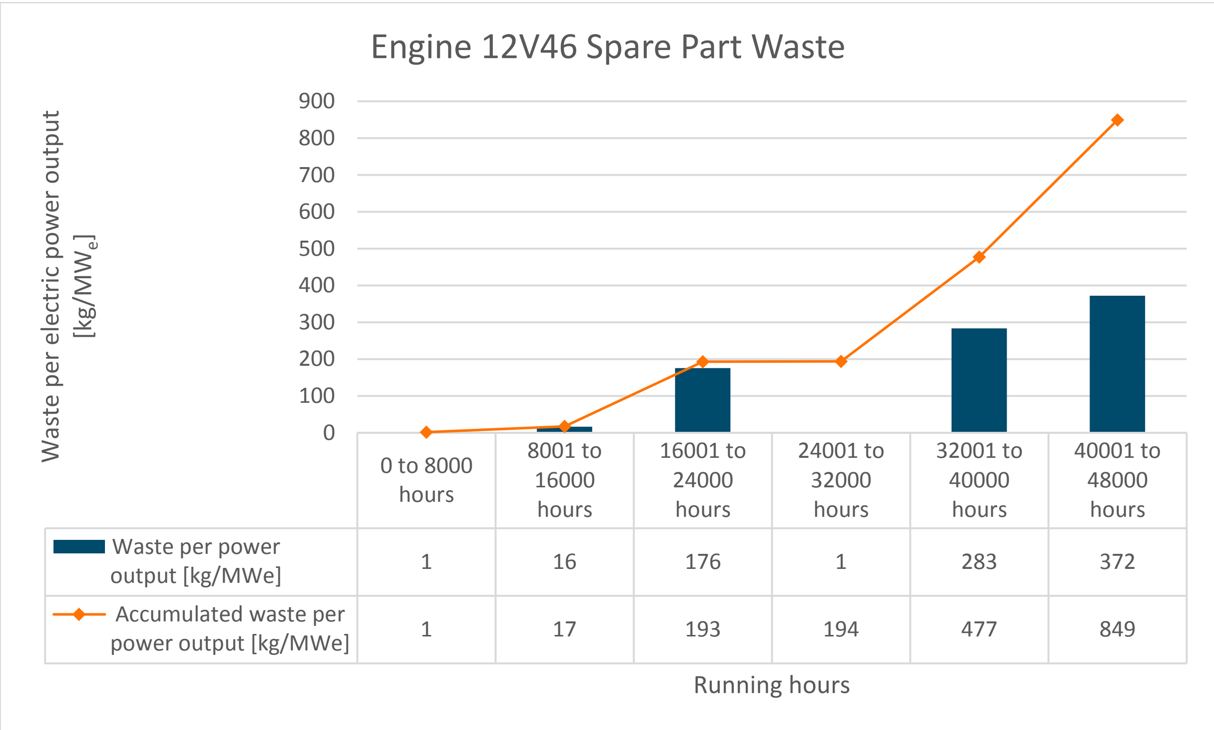


Fig. 15. Spare part waste generated during scheduled maintenance on an 12V46 engine.

4.2.12 Engine 18V46

Table 14 below shows calculation details used for engine 18V46. The calculation was done based on TPL76 weights.

Table 14. Calculation details for engine 18V46.

18V46		
Fuel	**Total electric output [MW_e]**	**Turbocharger**
HFO 2	17.08 (900 ppm NOx)	TPL76

The chart in Fig. 16 shows the spare part waste generation during each 8 000 hours period and the accumulated spare part waste generation during 48 000 hours.

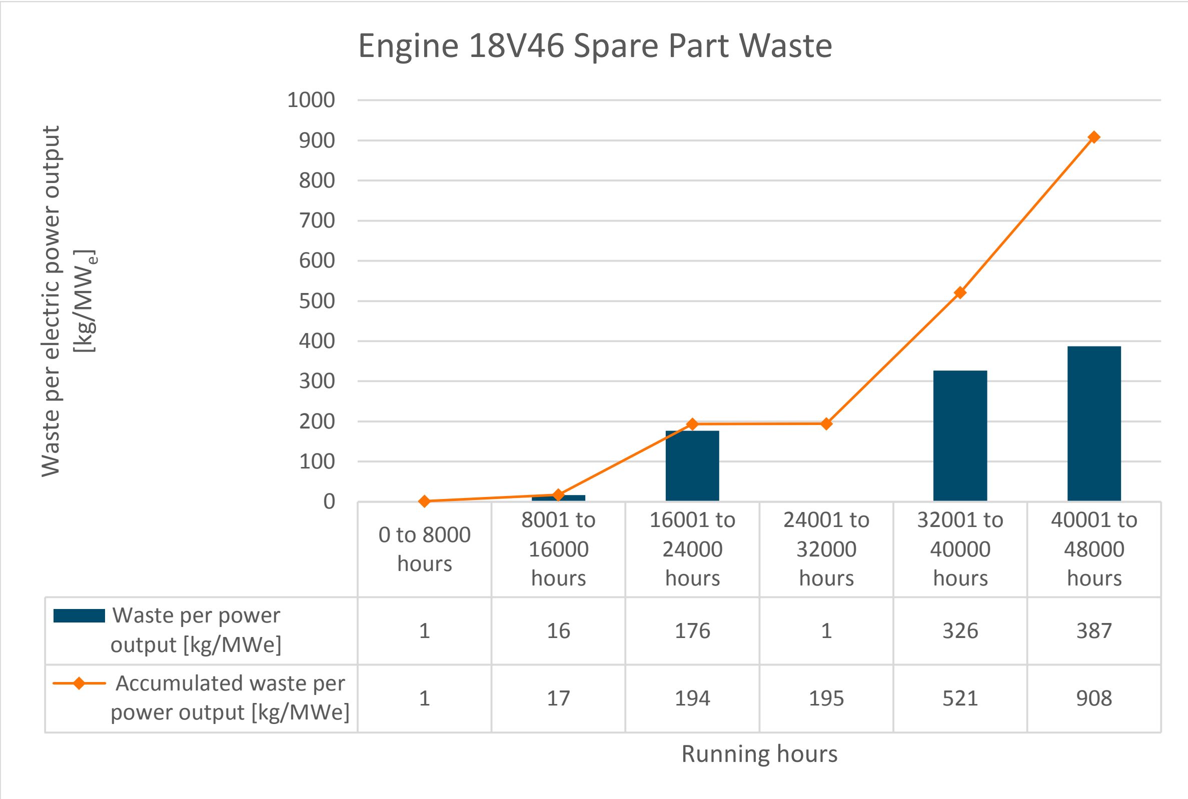
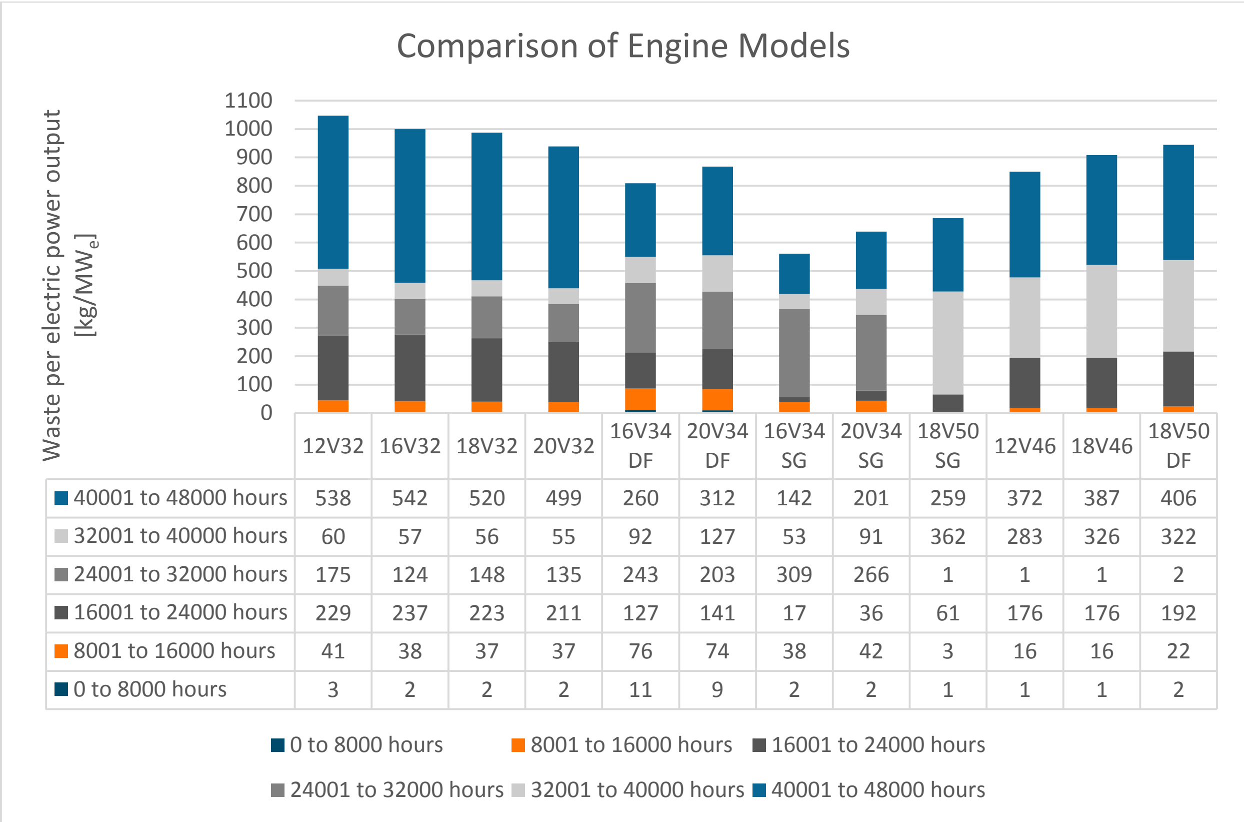


Fig. 16. Spare part waste generated during scheduled maintenance on an 18V46 engine.

The spare part waste accumulated during a lifecycle of an 18V46 engine is 908 kg/MW_e, which is more than the 849 kg/MW_e generated by the smaller 12V46 engine during one lifecycle. The explanation is that the TPL76 turbocharger has heavier parts than the TPL73 of the 12V46 engine, this gives at least 90 kg/MW_e more accumulated spare part waste for the 18V46 engine. The total amount of spare part waste from an 18V46 engine during one life cycle is 15 513 kg.

4.2.13 Engine Model Comparison

The chart in Fig. 17 shows a comparison of the engine models. From the table it can be seen how much spare part waste is generated per each engine model during the six 8000 running hour periods, as well as the total accumulated spare part waste per electric output.



	12V32	16V32	18V32	20V32	16V34 DF	20V34 DF	16V34 SG	20V34 SG	18V50 SG	12V46	18V46	18V50 DF
40001 to 48000 hours	538	542	520	499	260	312	142	201	259	372	387	406
32001 to 40000 hours	60	57	56	55	92	127	53	91	362	283	326	322
24001 to 32000 hours	175	124	148	135	243	203	309	266	1	1	1	2
16001 to 24000 hours	229	237	223	211	127	141	17	36	61	176	176	192
8001 to 16000 hours	41	38	37	37	76	74	38	42	3	16	16	22
0 to 8000 hours	3	2	2	2	11	9	2	2	1	1	1	2

Fig. 17. Comparison of the spare part waste generated due to scheduled maintenanc by the twevle studied engine models (DF engines running on HFO).

The engine with the greatest mass of spare part waste per Megawatt electric output is the 12V32 engine with 1047 kg/MW_e. This is expected, since it runs on HFO and has the smallest electric output. The trend among the 32 engines is as expected; the more cylinders an engine has, the smaller the amount of generated spare part waste per electric output. For the 34DF, 34SG and 46 engines the same trend would be expected; the more cylinders, the less the spare part waste per engine should be. According to the calculations this was however, not the case, but as described above it was found that the explanation – to a great extent at least – lies in the turbocharger spare part weights.

The engine with the smallest amount (560 kg/MW_e) of spare part waste per Megawatt electric is the 16V34SG engine in combination with the NA307 turbocharger. It could have been expected that the 20V34SG would have had more favorable results than the 16V34SG, but as earlier mentioned this was not the case, due to the heavier turbocharger spare parts of NA257.

It can also be noted that all the studied engine models running on HFO have got a spare part waste generation level of more than 800 kg/MW$_e$, according to their planned maintenance schedule. In comparison all the studied engine models running on gas have got a spare part waste generation level of less than 700 kg/MW$_e$.

4.3 Auxiliary Systems Waste Case Study

The engine auxiliary systems of a power plant consists of different pumps, feeders, air compressors, tanks, heating units, filters, etc. The schematic picture in Fig. 18 below gives an overview of what the auxiliary systems of a 20V32 engine looks like; the auxiliary systems of an 18V46 engine, the engine type in the studied power plant, is quite similar. The specific equipment making up the result of this case study is found in Tables 25-37 Appendix H.

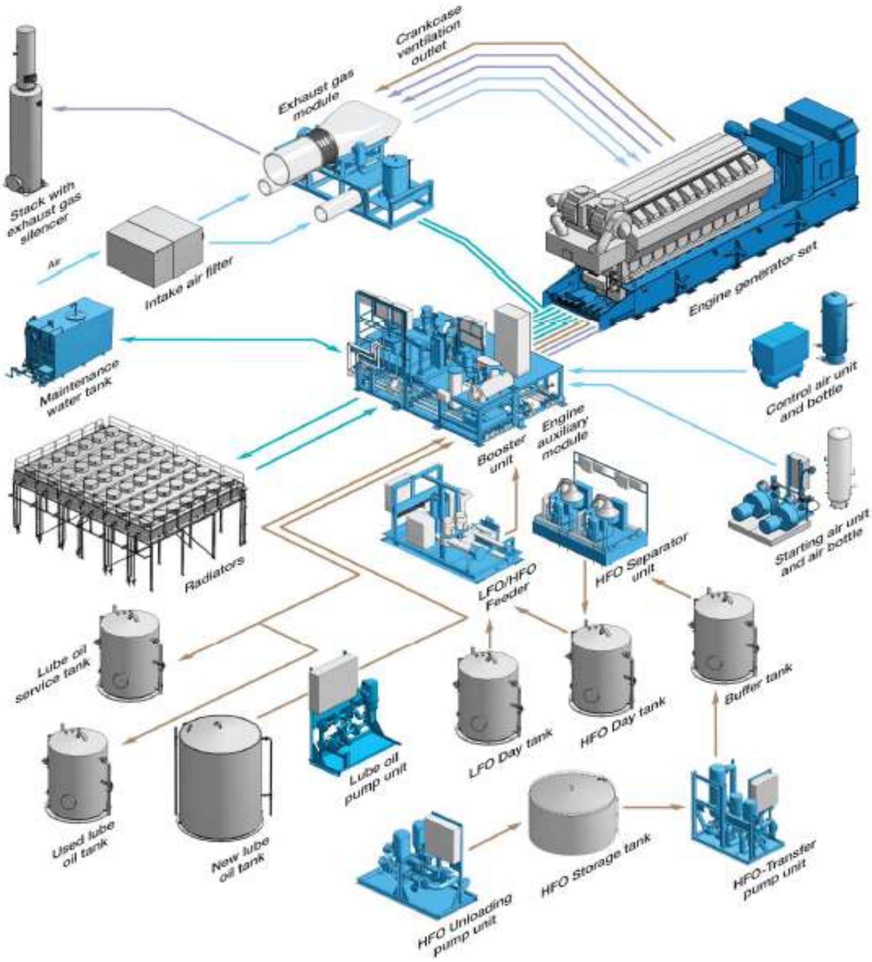


Fig. 18. Overview of the auxiliary systems of an 20V32 engine [25, Figure 31, pp. 26].

The power plant, which consists of seven 18V46 engines and has a total installed capacity of 120 MW, was chosen for the case study since it is fairly well documented in Maximo. When the case study was conducted the power plant had been running for about five years. In the calculations the power plant was for simplicity taken to have been running for exactly 60 months (5 years).

In a discussion on February 2, 2016 Rune Örn told that during its first years of operation the power plant was running on base load, but that nowadays the dispatch is less. Nowadays only one engine at a time is running, this has been the case for the past two years and it seems to continue in the same manner. The low dispatch results in less maintenance work. The amount of total running hours per engine as of March 10, 2016, are found in Table 15 below.

Table 15. Number of total running hours per engine as of March 10, 2016.

Engine	Running hours [h]
1	22 353
2	11 985
3	21 058
4	13 570
5	14 985
6	18 488
7	23 237
Engine average	17 953

4.3.1 Calculation

The data collection method is described in the Method subchapter 3.2. Auxiliary Systems Spare Part Waste. The raw data list exported from Maximo was split into separate lists for different groups of auxiliary equipment and posts which would not result in any replacement of parts were deleted [e.g. changing oil, washing filters, equipment inspection (with no suggested spare parts)]. The data sheets for the different auxiliary equipment groups are found in Appendix H. The text in orange was not found in Maximo, but was added since it was found in the Maintenance Manual for Auxiliaries [26]. A description of the data given in each column is found in connection to Table 25 in Appendix H.

The calculation of the weight per row in Appendix H was done according to equation (2)

$$\frac{60}{f} * n_{AR} * SPW * n_E = W_{R,tot} \text{ [kg]} \tag{2}$$

Where 60 is the total amount of months, f is the frequency i.e. with how many months' interval a work is done, n_{AR} is the amount of a specific item (part) actually required for the work, SPW is the item weight, n_E is equipment quantity and $W_{R,tot}$ is the total weight per row. The first part (60/f) of the equation allows for the number of replacements during five years not to be integers, but the effect of this was deemed to have a negligible impact on the accuracy of the study. If the value of $W_{R,tot}$ was larger than 20 kg a correction was made on that row. For further explanation regarding the equation see Table 25 in Appendix H.

The contact details of the suppliers that were contacted are found in Appendix I.

4.3.2 Calculation Results

Table 16 below shows the calculated amounts of the different waste types for each equipment group. The percentage of each waste type was found by dividing the total waste amount of the equipment groups (metal 713 kg, other 406 kg and hazardous 196 kg) by the total amount of waste (1 316 kg) and multiplying by 100.

Table 16. A summary of the mass of each waste type per group of auxiliary equipment.

Auxiliary equipment group	Metal [kg]	Other [kg]	Hazardous [kg]	Total waste per system [kg]
Ventilation system	28.04	0.04	0.00	28
Electrical system	0.00	0.00	0.00	0
Fire Protection	60.45	5.00	79.33	145
Sludge system	0.00	11.50	0.00	12
Auxiliary module	220.47	27.76	0.00	248
Air system	8.00	0.00	0.00	8
Fuel oil system	43.38	59.92	0.00	103
Lube oil system	92.08	56.34	0.00	148
Heat recovery system	6.00	120.50	0.00	127
Compressed air system	169.24	90.23	32.50	292
Emission monitoring	69.00	16.00	0.00	85
Water system	14.00	4.50	0.00	19
Black start unit	2.50	14.54	84.21	101
Total per waste type	**713**	**406**	**196**	**1316**
Percentage per waste type	**54%**	**31%**	**15%**	

The numerical results from the case study are visualized in the chart in Fig. 19.

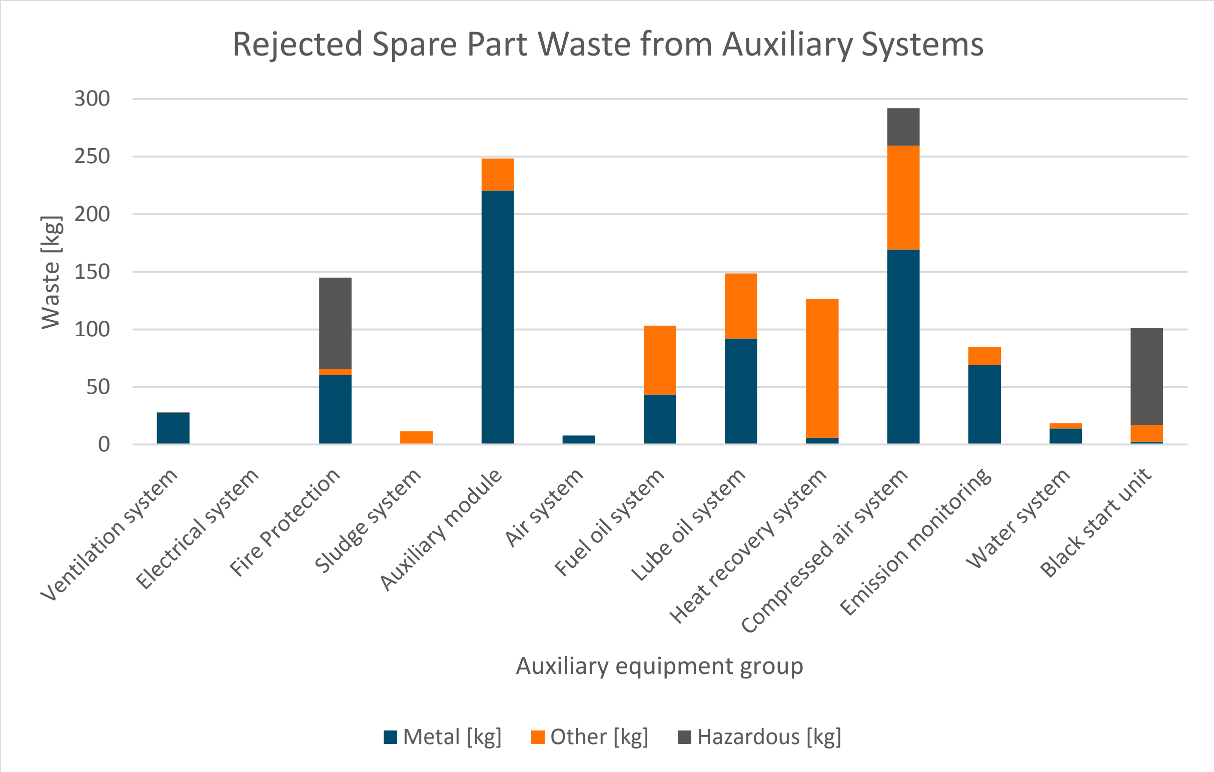


Fig. 19. Amounts of waste the auxiliary systems of the case study power plant have given rise to during the five years the plant has been in operation.

The auxiliary equipment groups producing the largest masses of waste in this case study were compressed air system, lube oil system and auxiliary module. In the compressed air system the largest posts by mass were overhaul kits for starting air units and oil filters for the instrument air units. Regarding the auxiliary modules the largest masses were made up by exchanged lube oil filter candles and cartridges and by joint kits and shaft seals for the lube oil pumps. In the lube oil system, repair and overhaul kits for the lube oil separator feed pumps and overhaul kits for the lube oil separators made up the largest waste masses.

Hazardous waste was generated from the fire protection and compressed air systems and from the black start unit. The hazardous waste from fire protection was batteries from the diesel fire engine and the fire detection panel. The compressed air system generates waste in the form of used oil filters, while the black start unit gave rise to used oil and coolant filters and batteries.

In this case study, of waste in the form of rejected spare parts from auxiliary systems, if was found that 54% of the spare parts was metal, 15% was hazardous and 31% belonged to the category other material. The suppliers did not report any of the spare parts, which have actually been exchanged, to be of the type electronic.

4.3.3 Auxiliary Systems versus Engines

Following the engine maintenance schedule for seven 18V46 engines having run the same amount of hours as the case study power plant engines, the engine spare part waste amounts presented in Table 17 would have been generated. The waste amounts up to the maintenance interval closest to the actual running hours, were applied; e.g. for engine 1 (22 353 hours) all spare parts changed up to 24 000 running hours were taken into account and for engine 3 (21 058 hours) all spare parts changed up to 20 000 running hours were included.

Table 17. Engine spare part waste generated according to engine maintenance service.

Engine	Running hours per March 10, 2016	Closest maintenance interval	Waste according to maintenance schedule
1	22 353	20 000 to 24 000	3 307
2	11 985	8 000 to 12 000	293
3	21 058	16 000 to 20 000	331
4	13 570	8 000 to 12 000	293
5	14 985	12 000 to 16 000	294
6	18 488	16 000 to 20 000	331
7	23 237	20 000 to 24 000	3 307
		Total	**8 154**

Adding the engine spare part waste of 8 154 kg and the auxiliary spare part waste of 1 316 kg gave a total of 9 470 kg spare part waste. This gave that 86% (8 154/9 470*100) of spare part waste would originate from the engines and 14% (1 316/9 470*100) would originate from the auxiliary systems. This calculation is experimental and should not in any case be seen as a rule.

4.4 Survey

The survey regarding solid waste – other than rejected spare parts – was sent to 152 contract managers. Of these, 63 were responsible for power plants with O&M contracts and 89 were responsible for maintenance contracts. The survey was e-mailed to the contract managers on January 21, 2016 and they were asked to collect data for a 28 day period (one month) and fill in the online survey on February 26, 2016 at the latest. The online survey was submitted by 33 respondents, of these 29 responses were complete enough to be included in the result calculations. Of these 29 responses, 28 were regarding power plants with O&M contracts and one was regarding a power plant with a maintenance contract. More details regarding the survey process is found in the Methods subchapter 3.3. Survey – Other Waste Types.

The results from the survey is presented in separate charts for non-hazardous waste, packaging waste, hazardous waste and electronic waste. Each power plant is represented by a number in the charts and the corresponding numerical results are found in Appendix J. Regarding gas power plants, eleven sufficiently completed responses were received and regarding HFO the number was 18. Power plant numbers 12 and 31 represent the average results for gas driven and HFO driven engine power plants respectively. Power plant numbers 28, 29 and 30 were reported to be peaking power plants. Oil, gas, ventilation and charge air filters, as well as SCR and oxidation catalyst elements are presented separately in Chapter 4.4.5 Filters and Emission Abatement Elements.

4.4.1 Non-Hazardous Waste

The respondents were asked to report the amount of solid non-hazardous waste (generally generated in control rooms, offices, social and sanitary facilities) accumulated during the survey period. Data was reported according to the following categories:

- Domestic garbage
- Paper (dry and clean)
- Glass
- Landfilling waste (e.g. mineral wool, PVC-plastic)
- Metal, excluding spare parts (e.g. empty containers, old tools)

The results for domestic garbage, paper and glass are presented in the chart in Fig. 20, since these waste types are assumed to be dependent on the amount of people working at the power plants the results were calculated as kg/person.

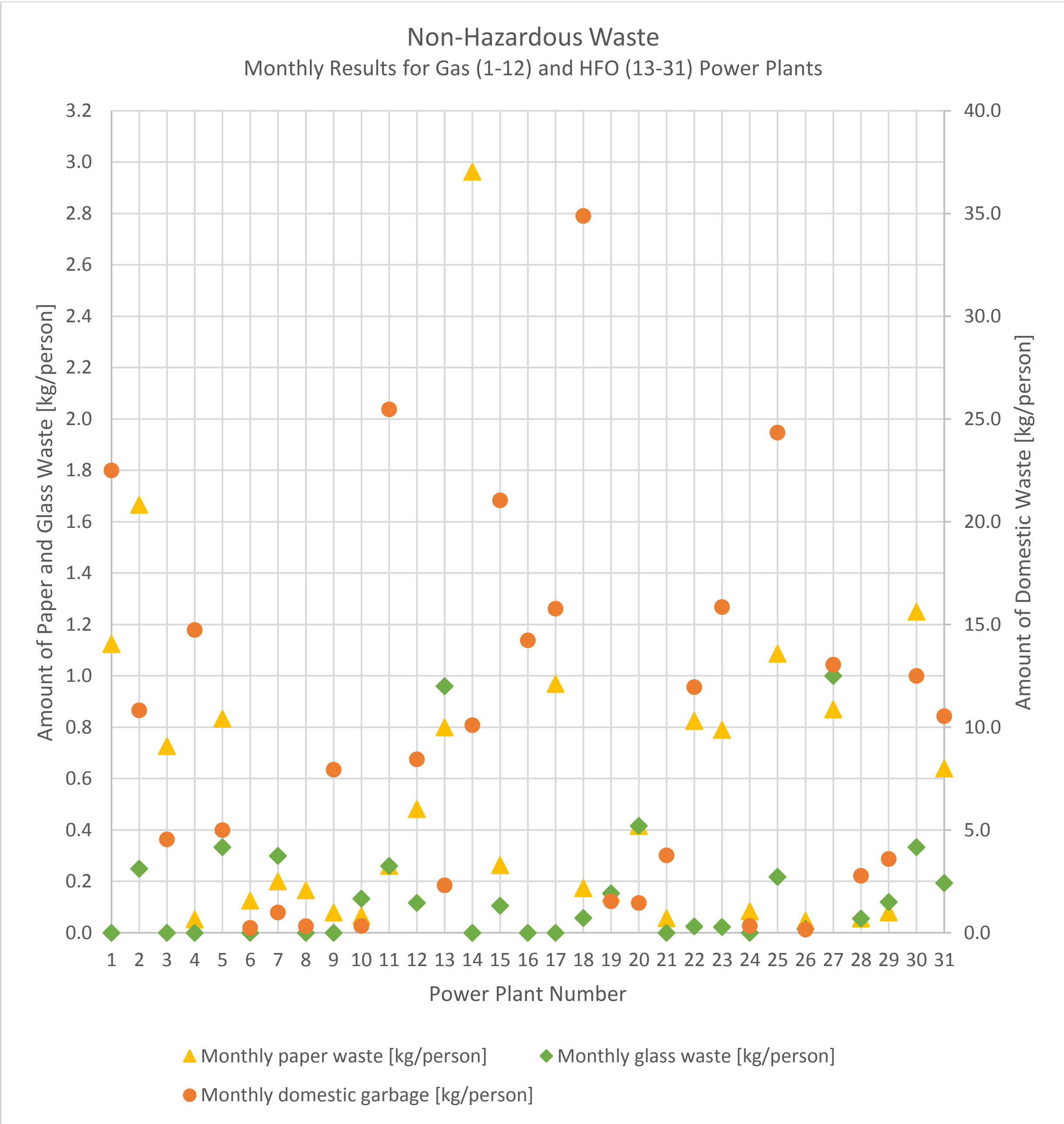


Fig. 20. Paper, glass and domestic waste produced per power plant worker and month.

The average results ("power plants number 12 and 31") for power plants running on gas and HFO respectively are 8.45 kg/person and 10.54 kg/person for domestic garbage, 0.48 kg/person and 0.64 kg/person for paper, and 0.12 kg/person and 0.19 kg/person for glass.

The paper waste figure for power plant number 16 was removed, since the figure (16.27 kg/person) was reported to include boxes, the figure was not included in the average. The domestic waste figure for power plant 4 was included in the average for domestic waste, but it was reported to include a smaller portion of landfilling waste as well. Some of the values e.g. domestic waste of power plants number 18, 11 and 25 are appearing to be a bit high. It should be considered that the respondents might have included waste, which actually belong to other categories, in this category. It might also be that e.g. a canteen is shared with another organization and then the result per power plant worker could appear higher than it actually is.

The results for landfilling waste and metal scrap – which are not spare parts – are presented in the chart in Fig. 21. The results are given as kg/MWh_e, since the waste generation is assumed to be more dependent on the power output than on the amount of personnel.

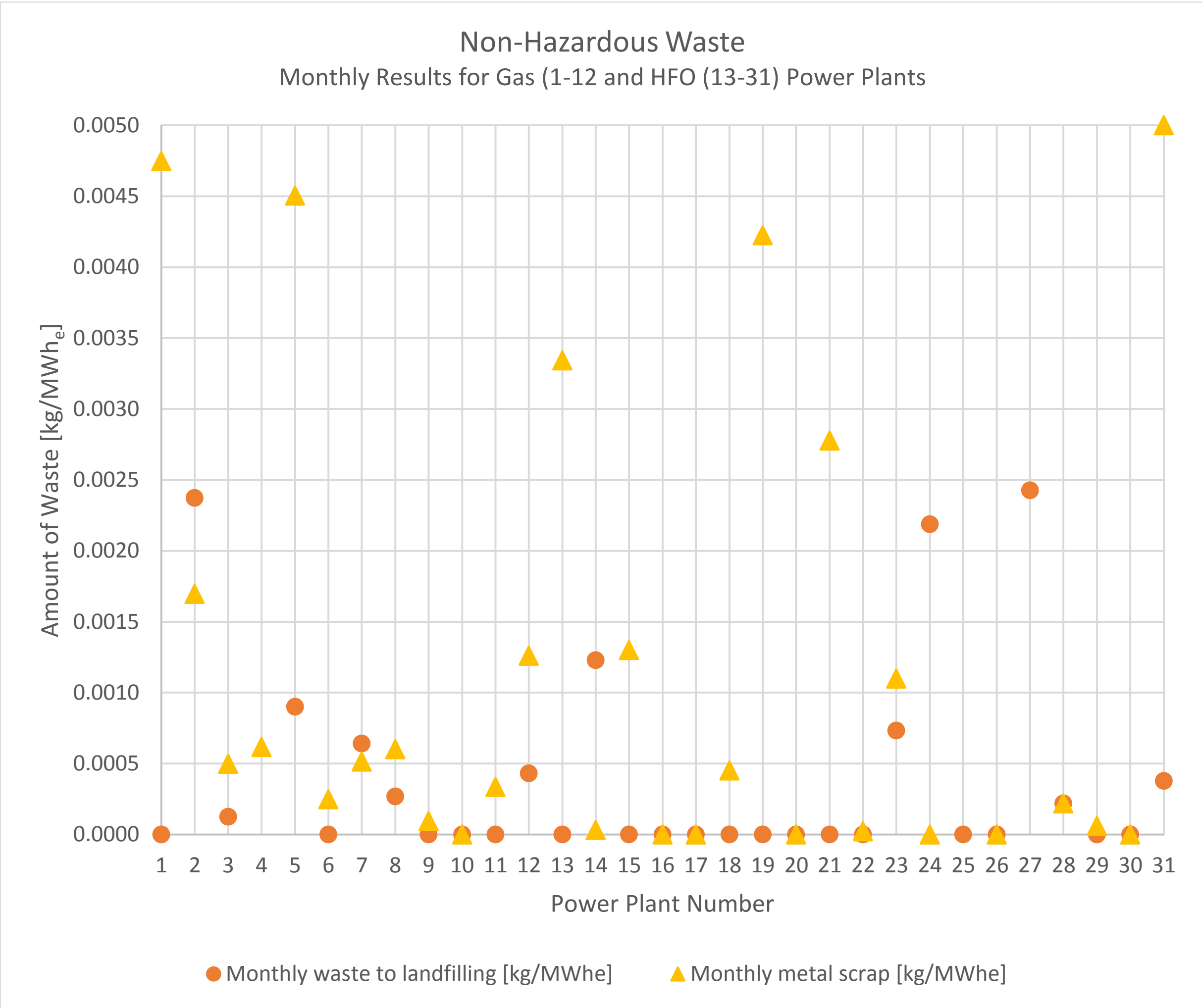


Fig. 21. Landfillig waste and metal scrap produced per electric output.

The average result regarding landfill waste is 0.0004 kg/MWh_e for both gas and HFO power plants and regarding metal waste the results are 0.001 kg/MWh_e and 0.005 kg/MWh_e respectively.

The landfilling waste of power plant number 4 was reported together with domestic waste and is not included in the gas power plant average of landfilling waste. The metal waste figures of 0.063 kg/MWh$_e$ and 0.023 kg/MWh$_e$ for power plants 25 and 27 were excluded from the chart for better chart accuracy, but were included in the average result for HFO power plants. The metal waste figure for power plant 25 was said to include rotted pipes and stanchions.

4.4.2 Packaging Material Waste

The respondents were asked to report the amounts of different types of packaging material accumulated during the survey period. The packaging material categories were the following:

- Cardboard
- Plastic
- Wood
- Polystyrene/Styrofoam

All the results regarding packaging waste are presented in the chart in Fig. 22. The average results for gas and HFO respectively are found to be 0.0010 kg/MWh$_e$ and 0.0013 kg/MWh$_e$ of cardboard, 0.0004 kg/MWh$_e$ and 0.0011 kg/MWh$_e$ of plastic, 0.0017 kg/MWh$_e$ and 0.0157 kg/MWh$_e$ of wood and 0.0016 kg/MWh$_e$ and 0.0006 kg/MWh$_e$ of polystyrene. According to the survey, the amount of packaging material waste is higher for each category – apart from polystyrene – for the HFO based power plants than for gas based ones. This is in line with the theoretical facts in Table 1 in Chapter 2.5.2 Engine Maintenance and Overhaul, which displays that the maintenance intervals for engines running on HFO are shorter than for engines running on gas. More frequent maintenance work should lead to more packaging waste from delivered spare parts.

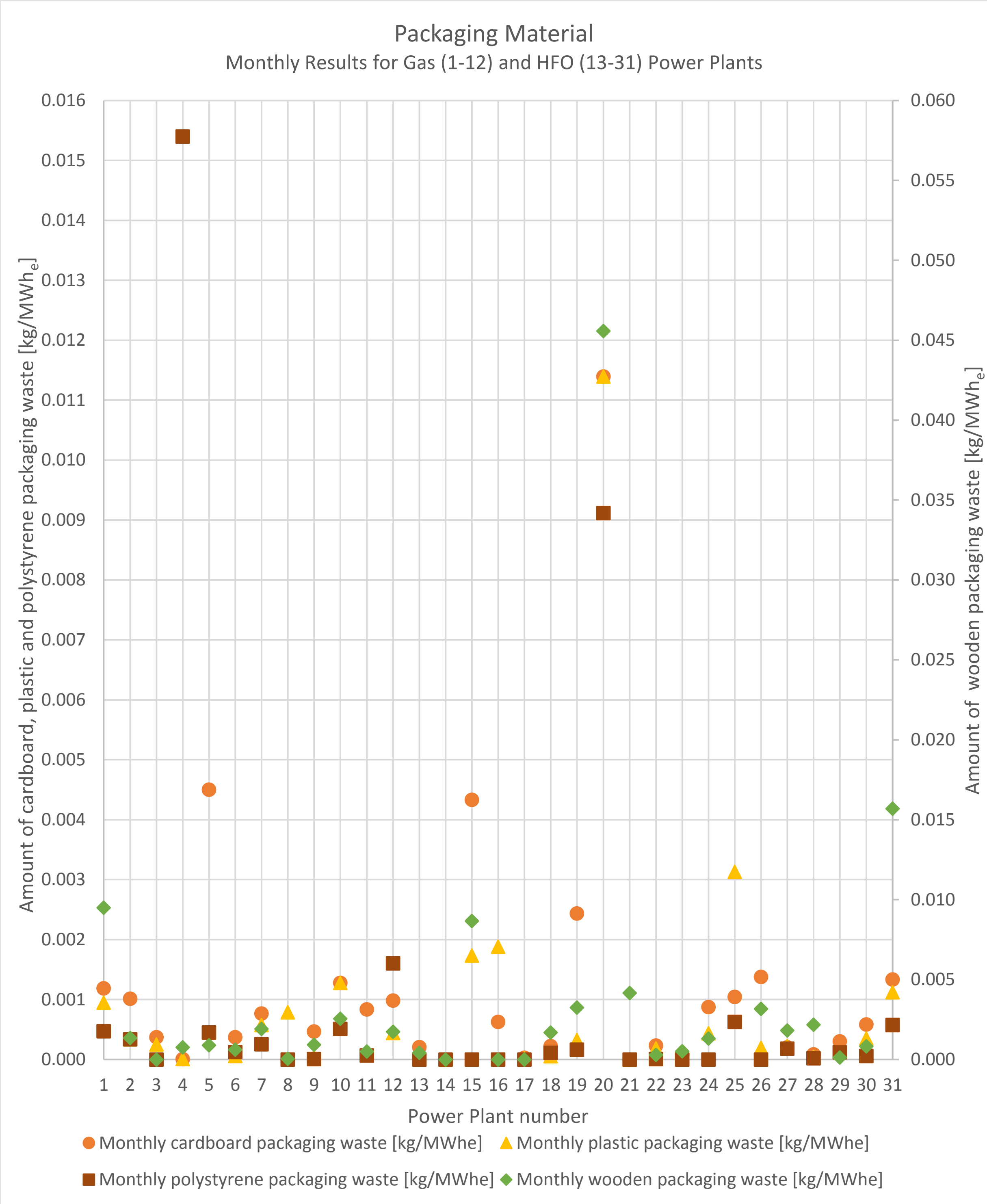


Fig. 22. Packaging material waste per electric output.

The wooden packaging waste figure of 0.21 kg/MWh$_e$, for power plant number 25 was removed from the chart for better chart accuracy. The figure was still included in the average calculation of wooden packaging waste from HFO power plants. Extensive maintenance work (for further description se Chapter 4.4.3 Hazardous Waste) was done on the engines, which could have led to the large amount of wooden packaging waste; also the amount of plastic packaging waste was larger for this power plant than for most of the others. For power plant 20 all the packaging waste categories got high results, this could be because of what is mentioned by the respondent: *"Low dispatch from the engines occasioned by the power transmission company and on-going maintenance activities that started around the same time."* A combination of low electrical dispatch and maintenance work could give high results for (spare part) packaging waste per electrical output. While all other power plants had reported polystyrene values between 0 kg and 10 kg, power plant number 4 had reported 200 kg. The respondent was asked to confirm the figure and confirmed that it was "similar waste", the figure is included in the gas power plant average.

4.4.3 Hazardous Waste

The respondents were asked to report the amounts of the following hazardous waste types, accumulated during the survey period:

- Rags contaminated with oil, solvents or other hazardous product
- Empty cans, containers and drums, which used to contain hazardous products
- Lighting equipment (e.g. fluorescent tubes and energy saving lamps) and lamp ballasts
- Batteries (e.g. nickel-cadmium and lead) and accumulators
- Other hazardous waste

The results for the two first points are presented in the chart in Fig. 23 and the results for the three latter points are presented in the chart in Fig. 24. In Fig. 23 it can be seen that the average amounts of contaminated rags are 0.0074 kg/MWh$_e$ and 0.0313 kg/MWh$_e$ for gas and HFO power plants respectively. The average amounts of contaminated containers are 0.0018 kg/MWh$_e$ for gas power plants and 0.0110 kg/MWh$_e$ for HFO power plants.

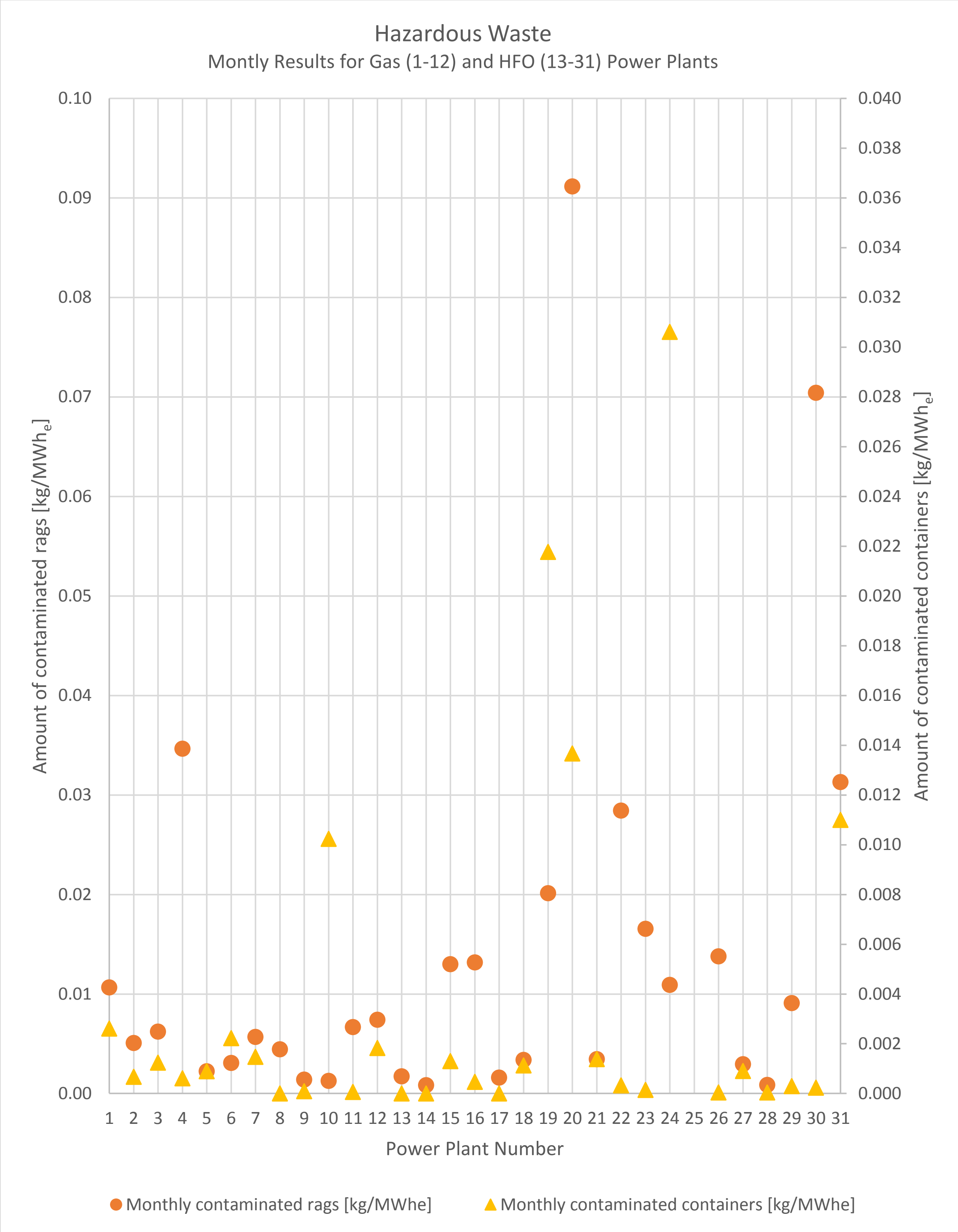


Fig. 23. Contaminated rags and containers per electric output.

The results for power plant 25 were very high compared to the results of the other power plants – rags 0.2611 kg/MWh$_e$ and containers 0.1253 kg/MWh$_e$ – and were removed from the chart for better chart accuracy, but the figures are included in the averages. The reason for the high figures was probably that a complete rehabilitation (including auxiliary equipment and replacement of two crankshafts) was done on the 10 MW power plant. Excessive maintenance work would lead to greater production of both used rags and empty containers, and also to lower electrical dispatch. The figures for power plant 25 were included in the HFO average result.

Fig. 24 shows the monthly results for lighting equipment, battery and other hazardous waste produced in gas and HFO power plants. The average monthly results for gas and HFO power plants respectively are 0.00028 kg/MWh_e and 0.00024 kg/MWh_e of lighting equipment waste, 0.00010 kg/MWh_e and 0.00007 kg/MWh_e of battery waste and 0.00016 kg/MWh_e and 0.00030 kg/MWh_e of other hazardous waste.

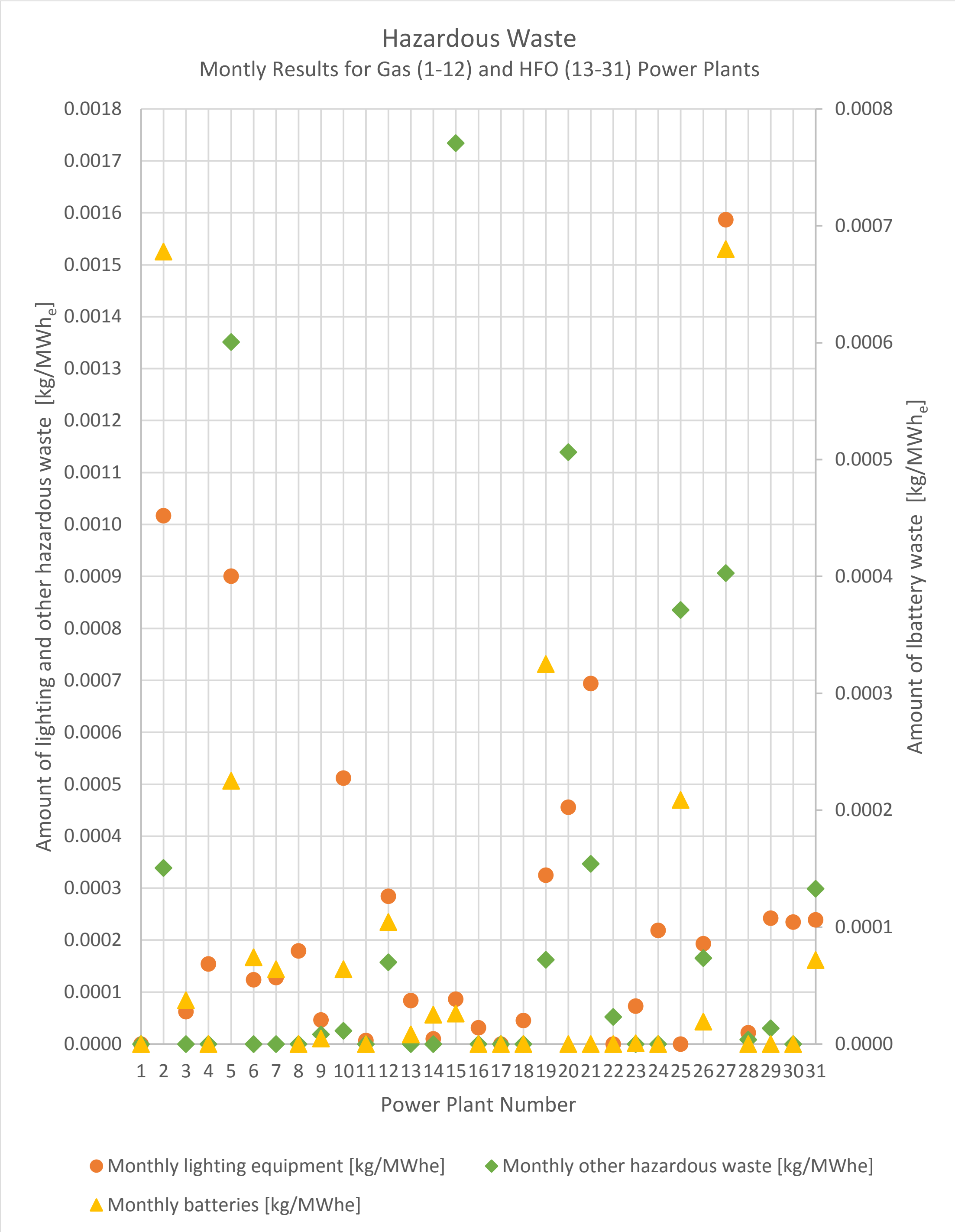


Fig. 24. Lighting equipment, other hazardous and battery waste.

Other hazardous waste types mentioned by the respondents were apart from printer toner cartridges, sludge build-up from filters and separator discs, oil cake from centrifugal filters and solids from charge air filters (hazardous in some cases). Of these waste types sludge build-up from filters and separator discs and oil cake from centrifugal filters are more likely to be generated at power plants running on HFO than on gas.

The amount of lighting equipment could also have been analyzed based on the area of the power plants, but the area data was not asked for in the survey.

Only power plants number 16 and 29 (both are HFO power plants) reported that they have an incinerator, which is in use. Power plant number 16 reported that 20 kg of oily sludge and rags was burnt during the survey period. Division with the electrical output of 31 862 MWh_e gave the result 0.00063 kg/MWh_e. Power plant 29 reported that 4 kg of oily sludge was burnt during the survey period and by dividing by the electrical output of 16 503 MWh_e the result 0.00024 kg/MWh_e was found.

4.4.4 Electronic Waste

The respondents were asked to report the amount of electronic waste such as old computers, printers, heaters and kitchen equipment accumulate during one year. They were asked to exclude spare parts.

The results are reported as yearly amount of electronic waste per person. The average results for gas and HFO power plants are 0.22 kg/person and 0.075 kg/person respectively. The average results and results per power plant are shown in the chart in Fig. 25.

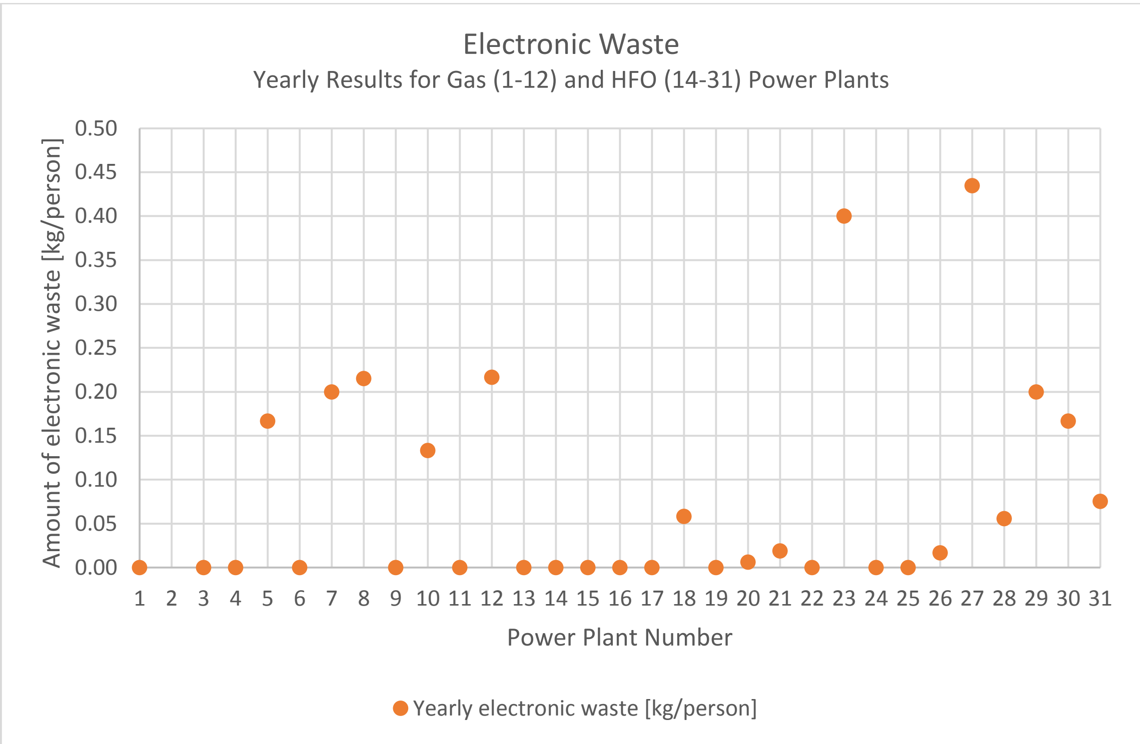


Fig. 25. Yearly electronic waste per power output.

The result for power plant number 2 of 1.67 kg/person was left out for better chart accuracy, but the figure was included in the average result for gas power plants. The electronic waste amount from power plant 2 was reported to include e.g. damaged printed circuit board, printer cartridge and electric (halogen and mercury) bulbs. The two latter wastes are actually hazardous waste.

The result for electronic waste should be used with caution, since the result is not reliable in the sense that some of the respondents have included waste which should probably be classified as spare parts. The electronic waste mentioned in the comment field were: Printer cartridge, printed circuit board, electric bulb, computer monitor, digital card, relay, circuit breaker, programmable logic controller, computer accessories, kitchen equipment, computer, printer, uninterruptable power supply (UPS), contactor, breaker and sensor.

4.4.5 Filters and Emission Abatement Elements

Process ventilation, charge air, gas and fuel oil filters (in case of 32-engine) were asked about separately in order to be able to utilize the information more flexibly. There was only little information concerning emission abatement elements in the responses, but it is still summarized at the end of this chapter.

Fuel Oil Filters

Most engines running on HFO have got washable fuel oil filters, but the 32-engines might have replaceable filters. Used fuel oil filters are characterized as hazardous waste by IFC, since they contain oil. Seven of the responses came from power plants with replaceable filters. The data regarding how many filters are changed per year is found in Table 18, together with data used for the calculations and other data, which might be of interest in this context. The calculation results can also be seen in the table.

The weights of the used filter elements were estimated with the help of the supplier. The filter types used in the power plants were checked from technical documentation. The first three power plants in the table have Finn Filter (nowadays Parker Hannifin) FFH-350 filters with three filter containers (max. nine filter elements per filter). The weight of one dry filter element is 1.54 kg and it was estimated that a used filter weights about 1.8 kg. The four latter power plants have DF2110 filters with two filter containers, from the same supplier. The weight of a new filter element of this kind is 2.3 kg and the estimated weight of a used filter is 3 kg.

The fuel oil filter waste per running hour was calculated according to equation (3)

$$\frac{n_{element} * W_{element}}{n_{h,tot}} = \frac{W}{h}\ [\frac{\text{kg}}{\text{h}}] \tag{3}$$

Where $n_{element}$ is the number of filter elements and $W_{element}$ is the weight of one filter element and $n_{h,tot}$ is the sum of the yearly running hours of all the power plant's engines.

When going through the responses it was found that the question regarding fuel oil filters had been expressed in a way which could be misunderstood, therefore the answers were double-checked with the respondents.

The calculation of average fuel oil filter waste is 0.0141 kg/h in power plants where the FFH-350 filter is used and 0.0020 kg/h in plants where the DF2110 filter is used. The average for both filter types together is 0.0072 kg/h. The difference between the average results of the two filter types is surprisingly big and partly the reason is probably coincidence, since the samples were so small. There might be great varieties in how often the filters need to be changed since the lifetime is dependent on many factors. To begin with the fuel might be of different quality, it might be contaminated by particles during transportation in tanks and pipelines, the fuel separation process in the power plant might work insufficiently, and mixing different fuel batches might create compatibility issues and cause asphaltenes to agglomerate and block filters. Fuel filter lifetime varies between power plants and even between different fuel batches, thus if one wants to estimate how much fuel oil filter waste there will be the at a certain power plant the fuel oil quality needs to be taken into consideration.

Table 18. Fuel oil filters replaced per year and generated waste amount per running hour.

Power plant number	Total installed capacity [MW]	Total number of running hours for all engines during year 2015 [h]	Engine model	Total number of engines	Number of replaced filter elements per year [pcs/year]	Weight of a used fuel oil filter element [kg]	Total weight of all used fuel oil filter elements [kg]	Amount of used fuel oil filter elements from all engines per running hour [kg/h]	Comments
FFH-350 (three filter containers)									
24	4.102	5840	12V32LN	1	72	1.8	129.6	0.0222	Confirmed by respondent.
30	22	19488	VAASA18V32	4	120	1.8	216	0.0111	Interpreted based response, HFO quality and maintenance recommendations. Discussion with Matts Friis 11.4.2016.
2	22	21771.3	VASA18V32	4	108	1.8	194.4	0.0089	Confirmed by respondent.
							Average per total running hours	0.0141	
DF2110 (two filter containers)									
28	63	52887	W18V32	9	18	3	54	0.0010	Confirmed by respondent.
16	48	49773	W20V32	6	12	3	36	0.0007	Confirmed by respondent.
17	26.19	27420.96	W20V32	3	24	3	72	0.0026	Interpreted based response, HFO quality and maintenance recommendations. Discussion with Matts Friis 11.4.2016.
20	80.32	4856	W20V32	10	6	3	18	0.0037	Confirmed by respondent.
							Average per total running hours	0.0020	

Gas Filters

The amount of gas filters per engine depends on the setup. Among the responses there were three different setups: two filter elements on the engine and one at the gas ramp, two filter elements at the gas module and one at the gas ramp, and finally two filters only at the gas ramp.

The filter changing frequency for gas filters both on the engines and gas pressure reduction station was asked for as times per year, but for the engines the answers were – with the help of Jan Krooks – converted into number of changed filters per year. The weight of a new filter element is 2 kg for both 34SG and 50DF and the weights of the gas ramp filter are 0.85 kg and 2.2 kg respectively. The filter weights were taken from technical documentation and 10% of the weight was added to represent build-up in the filter material. The calculations were done individually for each row. Table 19 shows the calculated data and the average result, which is 0.00089 kg/h.

Table 19. Gas filters replaced per year and waste amounts per running hour.

Power plant number	Total installed capacity [MW]	Total number of running hours for all engines during year 2015 [h]	Total number of engines	Engine model	Number of changed filters (on engine and ramp) [filters/year]	Total weight of all filters changed on engine and ramp [kg]	Amount of filter waste per running hous [kg/h]	Filter(s) on gas pressure reduction stations changed [times/year]	Total weight of used filters from pressure reduction station (based on respondent's estimate) [kg]	Amount of filter waste per running hours [kg/h]	Comments
6	5.832	6350	1	18V34SG	3	5.335	0.00084	1			
3	6	8556	1	W18V34SG	6	10.67	0.00125	2	5	0.00058	
8	26.25	41285	5	W18V34SG	15	26.675	0.00065	2	4	0.00010	
9	150	85806.6	16	W20V34SG	12	21.34	0.00025	0.25			
11	8.69	8272.06	1	W20V34SG	6	10.67	0.00129	2	4	0.00048	
2	53	40181	6	W20V34SG	24	26.4	0.00066	2	6	0.00015	Filter only at ramp
7	26.19	22693	3	W20V34SG	9	16.005	0.00071	1	5	0.00022	
10	175	114207	18	W20V34SG	72	79.2	0.00069				Filter only at ramp, no pressure reduction station
12	102	35063.9	6	W18V50DF	18	40.92	0.00117	0.5	1.5	0.00004	
5	100	19610.32	6	W18V50DF	12	27.28	0.00139				Filter at gas regulation unit rarely changed
						Average	**0.00089**		**Average**	**0.00026**	

The gas pressure reduction stations are usually not in Wärtsilä's scope of supply and then there is no information about them available. For the gas pressure reduction stations the information given by the respondents was used in unconverted form and the filter weights are based on the respondents' estimates. Power plants number 6 and 9 stated that the weight of a gas filter from the gas pressure reduction station are 20 kg and 12 kg respectively; these figures were not included in the average, since they seem too high to be held as likely. The corresponding figure for the gas pressure reduction stations is 0.00029 kg/h. Because of the limited information about the gas pressure reduction stations, the result for these should be used with caution.

Process Ventilation and Charge Air Filters

The respondents were asked to report the number of filter bags (as pieces of filter bags/year) changed in the process ventilation and charge air systems per year. Due to a mistake the unit times/year was used in the data collection sheet. The responses were gone through with Lars-Johan Andersson and knowing the circumstances mentioned above, the interpretation of the figures provided by the respondents was straightforward.

The weight of a used process ventilation filter bag was estimated to be 1 kg. Regarding the charge air filters there is a variety of types used and therefore the filter type of each power plant was checked in technical documentation found in IDM. The weights of combined oil wetted and jet pulse filter elements were checked with the supplier and additional weight of 10% was added to represent material collected in the used filters. The weight of an oil wetted and a jet pulse filter element is 4 kg and 22.7 kg respectively. The weights of used dry bag and dry roll filters were estimated.

The calculations were done according to equation (3) and the figures that were used are presented in Table 20, together with other data which might be of interest in this context and the results. The amount of used process ventilation filter waste accumulated was calculated to be 0.0044 kg/h for both gas and HFO power plants. Regarding charge air filters, the corresponding figures were 0.0136 kg/h and 0.0153 kg/h.

Table 20. Process ventilation and charge air filters replaced per year and waste amounts per running hour.

Power plant number	Total installed capacity [MW]	Total number of running hours for all engines during year 2015 [h]	Total number of engines	Engine model	Fuel mainly used during survey period	Number of process ventilation filters [pieces of filter bags/year]	Number of replaced charge air filters [filter bags/year]	Process ventilation filter weight [kg]	Charge air filter weight [kg]	Process ventilation filter amount per plant total running hour [kg/h]	Charge air filter amount per plant toal running hours [kg/h]	Charge air filter type and other comments
5	5.832	6350	1	W18V34SG	Gas	30	36	1	4.4	0.0047	0.0249	Combined oil wetted filter
2	6	8556	1	W18V34SG	Gas	30	20	1	2	0.0035	0.0047	Dry bag filter
7	26.25	41285	5	W18V34SG	Gas	450	3	1		0.0109		Charge air filter type unclear
11	102	35063.9	6	W18V50DF	Gas	324	90	1	4.4	0.0092	0.0113	Combined oil wetted filter
8	150	85806.6	16	W20V34SG	Gas	86		1		0.0010		Plain oil wetted filter (sludge, no used filters)
10	8.69	8272.06	1	W20V34SG	Gas	6		1		0.0007		Charge air filter type unclear
6	26.19	22693	3	W20V34SG	Gas	20		1		0.0009		Plain oil wetted filter (sludge, no used filters)
									Average per total running hours	0.0044	0.0136	
24	4.102	5840	1	12V32LN	HFO			1				Plain oil wetted filter (sludge, no used filters). Possibly no filters in process ventilation.
30	22	19488	4	VAASA18V32	HFO		384		2		0.039	Two stage dry filter
22	22	21771.3	4	VAASA18V32	HFO		16		10		0.007	Dry roll filter
27	85	36600	5	W16V46GDC2	HFO	540		1		0.0148		Plain oil wetted filter (sludge, no used filters)
28	63	52887	9	W18V32	HFO	100	10	1	24.97	0.0019	0.005	Jet pulse filter
15	200	91623	11	W18V46	HFO	525	720	1	4.4	0.0057	0.035	Combined oil wetted filter
18	165.285	77889	9	W18V46	HFO	0	540		4.4		0.031	Combined oil wetted filter. Ventilation filters are washable wire gauze filters.
21	120	11308	7	W18V46	HFO	0	0	1	4.4	0.0000	0.000	Combined oil wetted filter
26	90	46155	6	W18V46	HFO	324	180	1	4.4	0.0070	0.017	Combined oil wetted filter + inertial
16	48	49773	6	W20V32	HFO	180	96	1	4.4	0.0036	0.008	Combined oil wetted filter
20	80.32	4856	10	W20V32	HFO	0	0	1	4.4	0.0000	0.000	Combined oil wetted filter
13	381	77205	17	W20V46F	HFO	612	306	1	4.4	0.0079	0.017	Combined oil wetted filter
23	36.3	40458	5	W1632 (3) and W18V32 (2)		140	80	1	4.4	0.0035	0.009	Combined oil wetted filter
25	10	9799	3	W18V32 (1) and W6L32 (2)		0		1		0.0000		Plain oil wetted filter (sludge, no used filters)
									Average per total running hours	0.0044	0.0153	

In this context it could be mentioned that it has been observed (both earlier and in this study) that the process ventilation filters generally are changed to seldom. Regarding charge air filters the situation is a bit better, but in many cases still not satisfactory.

Emission Abatement Elements

None of power plants, regarding which complete responses were submitted, had an SCR installed. Two power plants, which were excluded due to missing information, have got SCRs installed. One of the power plants was handed over in January 2015 and there no SCR elements have yet been changed. This power plant uses ammonia which is delivered as bulk. The other power plant was handed over in March 2007 and there one SCR element was replaced after 16 000 running hours. This power plant uses urea, which is delivered in bags, but the respondent claims that the bags do not give rise to packaging waste.

The two power plants, which reported that they have SCRs, also have got oxidation catalysts installed. However, they have not replaced any oxidation catalyst elements yet, neither has a third power plant (handed over in May 2014) having an oxidation catalyst.

5 Conclusions

At Wärtsilä information regarding predicted amounts and types of solid waste is required when supporting the customers in conducting S&EA, applying for environmental permits and making waste management plans. The knowledge about waste generation has been limited and this was the first groundbreaking attempt to characterize and quantify solid waste from power plants. It was estimated that the one single regulatory framework, which the largest part of Wärtsilä projects adhere to, is the one of the IFC. Therefore the Performance Standards and EHS guidelines were chosen as the theoretical foundation for the thesis.

The results of this thesis are based on three partial studies: calculations of engine spare part waste based on twelve engine models' maintenance schedules, a case study of auxiliary systems spare part waste in the case study power plant, and a survey regarding other types of solid waste.

The large majority of the mass of rejected engine spare parts is metal, the small portion of other materials is mainly plastic and rubber. Calculations on spare part waste generation during the first life cycle, which corresponds to 48 000 running hours, were done based on the maintenance schedules for the 12 individual engines. After the first lifecycle the spare part replacement pattern is repeated. It should be noted and remembered that *pistons, cylinder linings and cylinder heads are not replaced during the first lifecycle*. When these are replaced, which happens rarely due to their long lifetime, there will be a peak in engine spare part waste generation. When Wärtsilä O&M performs maintenance work on engines (and other equipment) the old spare parts are washed and the customer can sell the metal for recycling.

The chart in Fig. 17 includes all the 12 studied engine models and shows the total amount of rejected spare part waste per MW_e, as well as the amounts for the six first individual 8 000 hour intervals. It was expected that of the engine models of the same engine type (32, 46, 34SG and 34DF) the engines with more cylinders would produce less waste per MW_e; however, it was found that this was not automatically the case. An at least partial reason for this was found to be the heavier turbocharger spare parts of the larger engines.

When looking at the first lifecycle the 12V32 engine generates totally 1 047 kg/MW_e, which is the highest figure for spare part waste per electric output and the 16V34SG engine generates the smallest amount 560 kg/MW_e. The highest total mass of spare part waste generated during the first lifecycle of an engine is 15 922 kg by the 18V50DF and the smallest amount is 4 252 kg by the 16V34SG. Finally it can be concluded that all the studied engine models running on HFO generate more than 800 kg/MW_e (max. 1 047 kg/MW_e) of spare part waste and the engines running on gas generate less than 700 kg/MW_e. It should however, be kept in mind that these calculations were made based on scheduled maintenance and sometimes if it is found that parts scheduled to be replaced are in good shape, they are not changed. It also happens that problems occur and unscheduled maintenance has to be carried out.

In the survey the following non-hazardous waste categories were included: domestic garbage, clean and dry paper, glass, landfilling waste and metal scrap (excluding spare parts). Used process ventilation filters and packaging material (cardboard, wood, plastic and polystyrene/Styrofoam) were asked about separately. The results for domestic garbage, paper and glass was calculated as average per person, since amount was assumed to depend mainly on the amount of people working at the power plant. The results for all the three categories were higher for the power plants running on HFO. Here the fuel type was not expected to affect the results; the difference could be because of chance, question interpretation issues or possibly the living habits at different occasions. When using the figures to estimate waste generation, one suggestion would be to find the joint averages of HFO and gas power plants for the three categories and utilize those figures.

Apart from the three categories mentioned above and the filters, all results were calculated as kg/MWh_e. The results regarding waste to landfilling was the same for both HFO and gas power plants and concerning metal (excluding spare parts) the result was five times higher for HFO power plants. The HFO power plants got higher results for all packaging waste categories, apart from polystyrene (NB see Chapter 4.4.2. Packaging Material Waste). Packaging waste would in many cases be the result of engine or auxiliary systems maintenance. Theoretically at least, more maintenance work need to be performed on HFO engines than on gas engines, this fact would support the mainly larger amounts of packaging material reported from HFO power plants.

Regarding electronic waste the result per person was higher for HFO power plants than for gas power plants. However, it was found that many of the respondents had included parts which were probably spare parts. Therefore the results should probably not be used for estimating how much electronic waste will be generated in e.g. offices and social facilities.

Regarding the different filter types it was studied how much filter waste is generated per running hour. In the case of used process ventilation filter waste it was found that the accumulated waste amount was 0.0044 kg/h for both gas and HFO power plants.

Apart from the process ventilation filters, all studied filter types should at least in some cases be disposed of as hazardous waste (fuel oil filters are always classified as hazardous waste). The same goes for oxidation catalyst elements and ash from incinerators. SCR elements are always hazardous waste. Other hazardous waste categories asked about in the survey were contaminated rags, empty containers (which used to contain hazardous products), lighting equipment and lamp ballasts, batteries and other hazardous waste. The results were much higher for HFO power plants than gas power plants in the case of contaminated rags and containers. In the case of other hazardous waste, the result for HFO power plants was almost two times the result of the gas power plants. Regarding lighting equipment and batteries the results were slightly higher and higher respectively for the gas power plants.

The replacement interval of fuel oil filters is highly dependent on the fuel oil quality, thus the fuel oil quality needs to be considered when estimating the amount of hazardous waste in the form of fuel oil filters. For the seven power plants based on 32-engines the average fuel oil filter waste generation was calculated to be 0.0072 kg/h. Regarding gas filters the joint average result for the three different filter setups was 0.00089 kg/h. The result for gas pressure reduction stations should be considered less trustworthy; the information found within Wärtsilä regarding the equipment is limited and the received data seemed to contain some errors, which could not be evaluated due to the lack of information. Concerning charge air filters the calculations gave that the filter waste generation per running hour was slightly higher for HFO power plants than for gas power plants.

When a new power plant is being planned and the customer can tell roughly how much personnel they will have and how many running hours and how much electric output they plan to achieve during a year the calculated average results could possibly be used to carefully make a very rough estimate of the expected solid waste generation. The estimate should be evaluated case by case and seen only as indicative.

A case study of a power plant, which consists of seven 46-engines, was made. The power plant has been operating for about five years. In the beginning it was running on base load, but due to the development of other electricity supply sources in the country only one engine at a time has been running during the last two years. The case study showed that – in the case of this specific power plant – 54% of the rejected spare parts from auxiliary systems were mainly metal by mass, 14% was hazardous waste and 31% were of other waste types. None of the spare parts which have been replaced so far were of the type electronic. The hazardous waste, which was batteries and used oil and coolant filters, originated from the fire protection system, compressed air system and the black start units. The chart in Fig. 19 shows the amounts and types of the different waste types per the equipment groups.

If the engine maintenance schedule had been followed for the engines, the rejected engine parts would stand for 86% of the spare part waste and the auxiliary system would stand for 14%. It should be remembered that this auxiliary system spare part results merely are the results of a case study and it is unclear if any general conclusions could be drawn based on this information. To get reliable foundation results similar studies should be made on several power plants.

6 Discussion

The hope is that the results of the studies made for this thesis shall be of use to Wärtsilä and that the summary of what the IFC says about solid waste in their Performance Standards and EHS guidelines shall support employees working with solid waste related questions. This thesis probably does not say everything there is to be said about solid waste from power plants and the work on the topic should be continued. However, results from the studies should be a good foundation for updating the general information in the solid waste statements for HFO and gas power plants and making them a little more detailed.

Although the power plants responding to the survey should make up some kind of average regarding the age of the power plants, the habits of the power plant workers, the amount of maintenance work performed, etc. it would still be good to conduct a study which would span over a longer time period. It would also be interesting to use the acquired results for making an estimate regarding how much solid waste that will be produced at a certain power plant and then compare the results of the estimate with the actual amount of waste produced. It would also be interesting to collect more detailed information about the different kinds of filters used and conduct a separate study on them.

The methods for conducting the partial studies generally worked in a satisfactory way, but there could still have been room for improvement. Regarding the engine spare part calculations it would have been good to have as the starting point to try to get the latest revision with standard turbocharger for as many engines as possible. If no engine of the latest revision had yet been built an engine of an earlier revision could have been chosen. This might not have affected the results very much, but still it would have been a good rule to follow.

When making the survey the ideal way to proceed would have been to start by making the data collection sheet, polish it and then make the online survey; however, the idea of making a data collection sheet for the respondents came up later. Working with the data collection sheet and survey parallel was probably more time consuming and some errors sneaked in, which made it more difficult to interpret the results (some respondent confirmation and expert help was needed). Collecting the data without data collection sheet would, however, probably have been very difficult. It is also hard to say to what extent the respondents have understood the questions and waste categories in the expected way and how much effort they have made to find and report real data. Putting together the survey it would also have been good to possess more thorough technical knowledge about Wärtsilä products and power plant setups.

The power plant in question was chosen as the case to be studied regarding auxiliary systems spare part waste, based on the fact that it was one of the better documented cases in the Maximo database. The results from the case study might still have been more useful if a power plant having run on base load for at least 48 000 hours would have been chosen for the study. The work with the case study took more time than expected, since it was not all that easy to get the required data from all the suppliers. It would have been much easier to conduct the work with the case study if the spare parts had been found in some Wärtsilä database in connection to a spare part number also found in Maximo. The appointed power plant was still a good choice in the sense that the contract manager was very helpful and easy to cooperate with. It would be interesting to conduct a similar study, not only on a HFO power plant running on base load, but also on a gas power plant. This could be done when the “bookkeeping” of scheduled and performed maintenance has been further improved.

During the process some other suggestions of topics for further research have been mentioned: A study regarding waste generated at power plants utilizing LFO and other fuels (now the responses from power plants mainly using these fuels were too few), a study on liquid waste and contaminated water from power plants, a study of reality versus engine maintenance schedules, lube oil system versus fuel oil system in the context of waste generation and differences in waste generation between power plants in different countries.

Working with thesis I have learned a lot about e.g. Wärtsilä technology, IFC and waste generated at power plants. I have also gotten to know a lot of people, learned how to find information within the company and gotten a lot of insights into how to do research. I am also quite sure that the people who have been involved in the work around this thesis have learned new things and I hope that the survey raised awareness regarding waste issues at the power plants.

Acknowledgements

I want to thank Wärtsilä for the opportunity to write this thesis, especially I want to thank team leaders Raymond Walsh and Eirik Linde for making it possible. I am also deeply grateful to my supervisors Piia Hannuksela and Katju Penttilä for their friendly and professional support throughout the process. The work with this thesis has required input from numerous persons working within Wärtsilä and I owe each and every one of you a great thank you for giving me of your time. I also want to thank my husband for encouraging me throughout my studies.

I want to dedicate this work to my father Fredrik, who took me to for a visit to the technical college already when I was five months old, guessed I would become an electrician when I was a kid and told me "just wait and see, you will still become an engineer one day" when I was in my youth. Well, you were right!

7 References

[1] Christensen, T. H. et al., *Solid Waste Technology & Management.* West Sussex: John Wiley and Sons, 2010. Ebrary.

[2] Wärtsilä, "History", *Wärtsilä homepage*, 2015. [Online] Available: http://www.wartsila.com/about/history. [Retrieved: December 2, 2015]

[3] Wärtsilä, "This is Wärtsilä", *Wärtsilä homepage*, 2015. [Online] Available: http://www.wartsila.com/about. [Retrieved: December 2, 2015]

[4] Wärtsilä, "Mission, Vision, Values and Strategy", *Wärtsilä homepage*, 2015. [Online] Available: http://www.wartsila.com/about/strategy. [Retrieved: December 3, 2015]

[5] Wärtsilä, "Mission, Vision, Values and Strategy", *Wärtsilä homepage*, 2016. [Online] Available: http://www.wartsila.com/about/strategy. [Retrieved: February 23, 2016]

[6] Wärtsilä, "Environmental Responsibility", *Wärtsilä homepage*, 2015. [Online] Available: http://www.wartsila.com/sustainability/environmental-responsibility. [Retrieved: December 3, 2015]

[7] The World Bank, "About the World Bank", *The World Bank homepage*, 2015. [Online] Available: http://www.worldbank.org/en/about. [Retrieved: December 22, 2015]

[8] IFC, "About IFC", *International Finance Corporation homepage*, 2015. [Online] Available: http://www.ifc.org/wps/wcm/connect/corp_ext_content/ifc_external_corporate_site/about+ifc_new. [Retrieved: December 22, 2015]

[9] IFC, "Sustainability Framework", *International Finance Corporation homepage*, 2015. [Online] Available: http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_site/Sustainability+and+Disclosure/Environmental-Social-Governance/Sustainability+Framework. [Retrieved: December 23, 2015]

[10] *IFC Performance Standards on Environmental and Social Sustainability,* IFC Overview of Performance Standards on Environmental and Social Sustainability, January 1, 2012

[11] IFC, "Equator Principles Financial Institutions", *International Finance Corporation homepage*, 2016. [Online] Available: http://www.ifc.org/wps/wcm/connect/Topics_Ext_Content/IFC_External_Corporate_Site/IFC+Sustainability/Partnerships/Equator+Principles+Financial+Institutions/. [Retrieved: February 23, 2016]

[12] *IFC Performance Standards on Environmental and Social Sustainability,* IFC Performance Standard 3 Resource Efficiency and Pollution Prevention, January 1, 2012

[13] IFC, "Environmental, Health, and Safety Guidelines", *International finance Corporation homepage*, 2015. [Online] Available: http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_sit

e/ifc+sustainability/our+approach/risk+management/ehsguidelines. [Retrieved: December 22, 2015]

[14] *Environmental, Health, and Safety Guidelines – Thermal Power Plants*, International Finance Corporation, Washington DC, 2008.

[15] *Environmental, Health, and Safety Guidelines – Air Emissions and Ambient Air Quality*, International Finance Corporation, Washington DC, 2007.

[16] *Environmental, Health, and Safety Guidelines – Waste Management*, International Finance Corporation, Washington DC, 2007.

[17] *Hazardous Waste Characteristics – A User-Friendly Reference Document*, United States Environmental Protection Agency, Washington DC, 2009.

Available: http://www3.epa.gov/epawaste/hazard/wastetypes/wasteid/char/hw-char.pdf

[18] Equator Principles Association, "About the Equator Principles", *Equator Principles homepage*. [Online] Available: http://www.equator-principles.com/index.php/about-ep/about-ep. [Retrieved: December 22, 2015]

[19] *IFC Performance Standards on Environmental and Social Sustainability*, IFC Performance Standard 1 Assessment and Management of Environmental and Social Risks and Impacts, January 1, 2012

[20] *A Guide to Biodiversity for the Private Sector* , International Finance Corporation – Environment and Social Development Department, Washington DC, year unknown.

Available: http://www.ifc.org/wps/wcm/connect/296ae980488551f5aa0cfa6a6515bb18/ESIA.pdf?MOD=AJPERES [retrieved: 30.12.2015]

[21] Parsons Brinckerhoff International Inc.

[22] M. Lindström, M. Anttila, T. Fitch, J. Pennanen, H. Salmenperä and T. Siberil, "Waste-related Conditions in Environmental Permits", Finnish Environment Institute, Helsinki, 2005.

[23] *Wärtsilä 34 SG Maintenance and Operation for High Performance,* Wärtsilä Corporation – Wärtsilä Engine Services, Helsinki, 2014.

[24] *Power Plant Genset Catalogue 2015*, Wärtsilä Corporation – Power Plants marketing, Helsinki, 2014.

[25] *Wärtsilä 32 Product Guide*, Wärtsilä Finland Oy – Power Plants, 2009.

[26] *Maintenance Manual for Auxiliaries*, Wärtsilä, 2010.

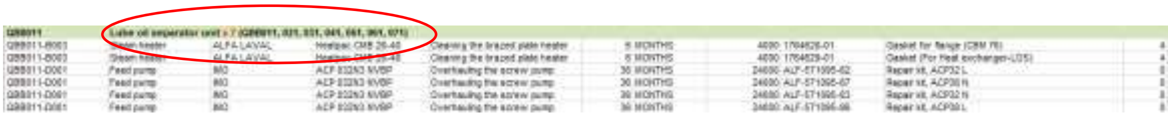
[27] *Internal guideline: Catalytic converter handling and disposal plan (DBAC379739)*, Wärtsilä, 2013.

Instructions

The excel file "To be sent_power plant Aux maintenance spare parts.xlsx" contains data, which has been retrieved from the Maximo database. The data has been gone through and the works and required spare parts (items) have been sorted on separate sheets according to systems.

Vent	El	Fire	Sludge	Air	Aux	Fuel	Lube	Heat	Eng.	Com. air	Water	FC

The data has also been completed with information in the Maintenance manual for auxiliaries (marked with orange), but the foundation is still what is found in Maximo. Some few sets of cells are marked with yellow and this means that there is a comment regarding the cell content. Sweep over the cell marked with a red corner to see the comment. The list has been sorted so that work title and parts related to it appear only once, although there might be many similar units requiring the same kind of maintenance, e.g. 7 lube oil separators. When following these instructions think about an average unit running according to the recent power plant running profile.

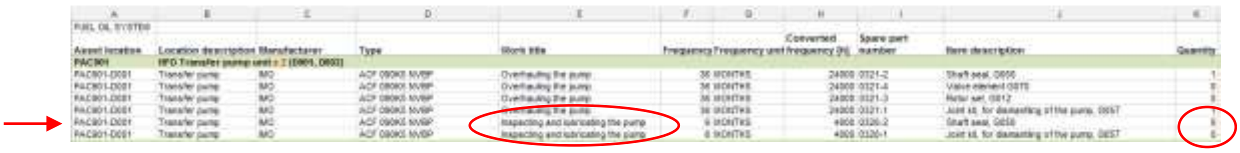


A "0" (zero) in column K means that the amount of a certain item needed is not specified neither in Maximo nor in the Maintenance manual. This is why your help is needed. Please go through the different system tables and replace the zeros with the amount of items you think is required for the work done on one unit under a certain work title. If a certain work is estimated to be carried out more seldom than stated in the list the quantity of spare parts can be given as <0.

If you find that some of the numbers which are not 0, are not correct please update those as well

E	F	G	H	I	J	K
Work title	Frequency	Frequency unit	Converted frequency [h]	Spare part number	Item description	Quantity
Overhauling the pump	36	MONTHS	24000	0321-2	Shaft seal, G050	1
Overhauling the pump	36	MONTHS	24000	0321-4	Valve element G070	0
Overhauling the pump	36	MONTHS	24000	0321-3	Rotor set, G012	0
Overhauling the pump	36	MONTHS	24000	0321-1	Joint kit, for diamantling of the pump, G057	1
Inspecting and lubricating the pump	6	MONTHS	4000	0320-2	Shaft seal, G050	0
Inspecting and lubricating the pump	6	MONTHS	4000	0320-1	Joint kit, for diamantling of the pump, G057	0

Example (⟶)



If the transfer pump PAC901-D001 in the fuel oil system is inspected and lubricated every 6 months and one (1) *Shaft seal, G050* and one (1) *Joint kit, for Dismantling of the pump, G 057* is needed replace the two "0" with "1".

If inspecting and lubricating the pump is actually done only every 12 months and one (1) *shaft seal, G050* and one (1) *joint kit for dismantling the pump, G050* is required for the work replace the two "0" with "0.5", in order to get the correct relation between 6 months and the quantity. If the work is done only every 24 months and both parts are then replaced, change the two "0" to

“0.25”. If inspecting and lubricating the pump is done every 6 months, but the parts replacement is done only every second or every fourth time you should also follow this example.

If inspecting and lubricating the pump requires e.g. 3 pcs of *shaft seal, G050* and the work is done every 12 months the “0” should be replaced with “1.5” (6/12*3). If the work is done every 24 months the “0” should be replaced with “0.75” (6/24*3).

Questions marked with an * are required

Survey regarding solid waste from power plants during the operational phase.

The survey as a whole considers waste generated from the complete power plant (engine hall, workshop, control rooms, offices, social facilities etc.) Please read the instructions carefully and do your very best to calculate/estimate the amounts of different types of waste generated. It is strongly recommended that you fill in the form "Waste Survey_Data collection sheet" attached to the e-mail before filling in the answers in this online survey.

The answers in the survey should be given for a period of four weeks (28 days). As an example the answers could be collected for the period Monday 25.1 to Sunday 21.2, but it is also possible to start a couple of days earlier or later. Please fill in this online survey on 26.2.2016 at the latest. If the waste generation has been studied before it is also an option to report using existing data. If you report previously recorded data please leave a comment in the comment field regarding the survey period in this online survey.

Respondents who have submitted a properly filled survey by 26.2.2016 have got the possibility to take part in a lottery where three nice gifts (a fine backpack with some additional surprises inside) are raffled. Check the box below if you wish to take part in the lottery.

I wish to take part in the lottery *

- ○ Yes
- ○ No

Thank you for filling in this survey!

Please note that due to technical limitations, it is not possible to go back in the survey. In the middle of the survey and at the end there is a possibility to leave comments in case you should notice that you want to comment on something you have stated earlier in the survey.

Period during which the waste generation was observed (totally 28 days):

Starting date (dd.mm.yyyy) *

Ending date (dd.mm.yyyy) *

Comments regarding the survey period (e.g. if earlier recorded data is reported)

Information about the respondent and the contract type:

Name *

Title *

E-mail address *

Phone number *

Contract type *

○ O&M contract

○ Maintenance contract

Information about the power plant:

Name *

Location (city/village and country) *

Wärtsilä project number (P/00000)

Running profile *

○ Peaking power

○ Base load

Total installed capacity [MW]

Total number of running hours [h] for all engines during survey period (28 days) *

Total number of running hours [h] for all engines during year 2015 *

Electric power output [MWh] for the whole power plant during the survey period (28 days) *

Average number of personnel [persons] during daytime (including those performing outsourced tasks) *

Average number of personnel [persons] during night time (including those performing outsourced tasks) *

Engine type

If there are several engine types in the power plant choose the type there are most of. *

○

32 HFO

- 34 SG
- 34 DF
- 46 HFO
- 50 SG
- 50 DF

Total number of engines *

Specify the engine model (e.g. W20V34DF)
If there are several engine types/models in the power plant write the number of engines in brackets after the engine model. Example: W20V34DF (6), W18V50SG (4).
*

If the most common engine type is 32 HFO, how often does it happen that a fuel oil filter on any of the engines is exchanged?
Give the answer as [times/year]

Estimate the weight of a used fuel oil filter
Give the answer in [kg]

Fuel mainly used during the survey period *

- HFO
- Gas
- LFO
- LBF

Gas engine specific questions:

Where are the gas filters situated? *

- At engine
- At gas module

How often does it happen that a gas filter is changed?
Give the answer as [times/year]
*

Estimate the weight of a used filter
Give the answer in [kg]
*

Does the power plant have gas pressure reduction station installed? *

- Yes

○ No

Are the filters from the gas pressure reduction station disposed of together with waste from the power plant?

○ Yes

○ No

How often does it happen that a filter on the gas pressure reduction station is changed

Give the answer as [times/year]

Estimate the weight of a used filter

Give the answer in [kg]

Possible comments regarding the gas pressure reduction station

If another fuel was also used during the survey period, specify the fuel

Does the power plant have heat recovery? *

☐ Hot water boiler

☐ Exhaust gas boiler

☐ Steam turbine

☐ For own consumption only

☐ None

Emission abatement:

Does the power plant have SCR? *

○ Yes

○ No

SCR specific questions:

Have any SCR elements been replaced, if so how many and after how many running hours? *

What is done with the used SCR catalyst elements?

In what form is the reagent for the SCR delivered to site? *

- Ammonia
- Urea

How is the reagent delivered? *

- Tanks/bulk
- Ready made liquid
- Bags (option for urea)
- Big bags (option for urea)

Does the reagent give rise to packaging waste? *

- No
- Yes, how much? [kg/month]

Emission abatement:

Does the power plant have oxicat (oxidation catalyst)? *

- Yes
- No

Oxicat specific questions:

Have any oxicat elements been replaced, if so how many and after how many running hours? *

What is done with the used oxicat elements?

Does the power plant have an incinerator? *

- Yes
- No

Which waste fractions are burnt in the incinerator? *

How much ash is generated by the incinerator?
Give the answer as [kg/month]
*

Is the ash from the incinerator defined as hazardous waste? *

○ Yes

○ No

What is done with the ash from the incinerator? *

Possible comments regarding the information given so far:

A. Solid Waste Disposal (Non-hazardous)

- When answering these questions try to exclude packaging material for spare parts, this will be asked about later
- The waste types in this section (A) are generally generated in control rooms, offices, social and sanitary facilities
- Pay attention to the units

Domestic garbage [kg/month]
Food scraps, small articles, plastic bottles and food packaging etc.
*

Paper [kg/month]
Dry and clean printing paper, magazines, newspapers etc.
*

Glass [kg/month]
Bottles and jars etc.
*

Waste to landfilling [kg/month]
What waste is landfilled varies between countries, sometimes the domestic waste (above) is also landfilled, but for this question think of inert waste like car tyres, mineral wool, PVC-plastic etc.
*

Metal scrap (excluding spare parts!) [kg/month]
Empty containers (that have not contained hazardous material), old tools etc.
*

Used ventilation filters [pieces of filter bags/year]

Used charge air filters [pieces of filter bags/year]

B. Packaging waste

- When answering try to estimate the amount of packaging material for spare parts only

- Waste in this section (B) is generally generated in workshops and engine halls

- Give all answers as [kg/month]

Cardboard (e.g. boxes) [kg/month] *

Plastic [kg/month] *

Wood [kg/month] *

Polystyrene/Styrofoam [kg/month] *

Was any maintenance or service work carried out during the survey period? *

- ☐ Engine Overhaul
- ☐ Maintenance/service work on engine
- ☐ Maintenance/service work on auxiliary systems
- ☐ Other service work on facilities
- ☐ No considerable maintenance/ service work was done

Comments regarding maintenance/service work done e.g. on what equipment it was done, on how many engines and what was done. *

What is generally done with the different kinds of packaging material, check the right option

	Reuse at site	Reuse by employees	Sent for recycling	Sent for incineration/disposal
Cardboard *	○	○	○	○
Plastic *	○	○	○	○
Wood *	○	○	○	○
Polystyrene/Styrofoam *	○	○	○	○

C. Solid Waste Disposal (hazardous)

- Waste is considered hazardous if it has any of the following characteristics: ignitability, reactivity, toxicity or if it is corrosive. Waste is also considered hazardous if it has some other physical, chemical or biological characteristics that might cause it to be dangerous to human health or the environment.

- Pay attention to the units

Rags contaminated with: Oil, solvent or other hazardous product [kg/month] *

Empty cans, containers and drums [kg/month]
Which used to contain hazardous materials like oil, solvents, paint etc.
*

Are some of the empty cans, containers or drums sent back to the supplier to be reused? *

- Yes
- No

Lighting equipment (e.g. fluorescent tubes and energy saving lamps) and lamp ballasts [kg/month] *

Batteries (e.g. nickel-cadmium and lead) and accumulators [kg/month] *

Other hazardous *solid* waste (excluding paper oil filters) [kg/month]
Examples could be e.g. printer toner cartridges and in some cases the solids collected in the oil wetted filter.

What does the "other hazardous waste" consist of?

Some questions regarding liquid waste: How big amounts of the below substances were disposed from the power plant site for treatment at contractor facilities during year 2015?

Sludge (oil) [m3]

Oily water [m3]

Used lube oil [m3]

Component washing solvents [L]

Cutting oil (if collected separately) [L]

Rejected closed circuit cooling water [m3]

Is the oily water treated at site?

- Yes
- No

D. Electronic waste

Electronic waste (excluding spare parts) [kg/year]
Computers, printers, heaters, kitchen equipment etc.
*

What does the electronic waste consist of? *

E. Other questions

How big an area [m2] is required for storing solid non-hazardous waste (excluding possible non-hazardous ashes)? *

How big an area [m2] is required for storing solid hazardous waste (excluding possible hazardous ashes)? *

Were there any extraordinary events during the survey period which might have had considerable impact on the collected data?

Possible comments regarding the latter part of the survey

These were the last questions, when you press "Continue" the survey will be submitted.

Questions? [redacted]

Survey Regarding Solid Waste from Power Plants during Operational Phase

This form has been developed to support the data collection, however after collecting the data please transfer it to the online survey found here. Transferring the data should take approximately 20 minutes.

This survey as a whole considers waste generated from the complete power plant (engine hall, workshop, control rooms, offices, social facilities etc.) Please read all instructions carefully and do your very best to calculate/estimate the amounts of different types of waste generated.

Any questions or comments can be sent to ….

Survey period

The answers in the survey should be given for a period of four weeks (28 days). As an example the answers could be collected for the period Monday 25.1 to Sunday 21.2, but it is also possible to start a couple of days earlier or later. Please fill in the online survey on 26.2.2016 at the latest. If the waste generation has been studied before it is also an option to report using existing data, in that case please comment in the comment field in the online survey.

Starting date ________________

Ending date ________________

Information about the respondent and contract

Name ____

Title ____

E-mail address ____

Phone number ____

Contract type __ O&M contract __ Maintenance contract

Information about the power plant

Please note that some of the questions refer to additional questions in section F in this form.

Name ____

Location (city/village and country) ____

Wärtsilä project number (P/00000) ____

Running profile __ Peaking power __ Base load

Total installed capacity [MW] __________

Total number of running hours [h] for all engines during the survey period (28 days) __________

Total number of running hours [h] for all engines during year 2015 __________

Electric power output [MWh] for the whole power plant during the survey period (28 days) _______

Average number of personnel [persons] during daytime (including those performing outsourced tasks) __________

Average number of personnel [persons] during night time (including those performing outsourced tasks) __________

Engine type
If there are several engine types in the power plant choose the type there are most engines of.

__ 32 HFO (see F.1, paper filters)	__46 HFO
__ 34 SG	__ 34 DF
__ 50 SG	__ 50 DF

Total number of engines __________

Specify the engine model (e.g. W20V34DF)
If there are several engine types/models in the power plant write the number of engines in brackets after the engine model. Example W2034DF (6), W18V50SG (4)

____

Fuel mainly used during survey period __ HFO __ Gas (see F.2) __ LFO __ LBF

If another fuel was also used, specify
____

Heat recovery	__ Hot water boiler	__ Exhaust gas boiler	
	__ For own consumption only	__ Steam turbine	__ None
Emission abatement	__ SCR (see F.3)	__ Oxicat (see F.4)	__ None
Incinerator	__ Yes (see F.5)	__ No	
Running profile	__ Peaking power	__ Base load	

A. Solid Waste – Non-hazardous

- When answering these questions try to exclude packaging material for spare parts.

- The waste types in this section (A) are generally generated in control rooms, offices, social and sanitary facilities.

- Pay attention to the units

Domestic garbage [kg/month] ___________
Food scraps, small articles, plastic bottles and food packaging etc.

Paper [kg/month] ___________
Dry and clean printing paper, magazines, newspapers etc.

Glass [kg/month] ___________
Bottles and jars etc.

Waste to landfilling [kg/month] ___________
What waste is landfilled varies between countries, sometimes the domestic waste (above) is also landfilled, but for this question think of inert waste like car tyres, mineral wool, PVC-plastic etc.

Metal scrap (excluding spare parts) [kg/month] ___________
Empty containers (that have not contained hazardous material), old tools etc.

Changing of ventilation filters [times/year] ___________

Changing of charge air filters [times/year] ___________

B. Packaging material

- *When answering, try to estimate the amount of packaging material from spare parts.*

- *Waste in this section (B) is generally generated in workshops and engine halls.*

- *Pay attention to the units*

Cardboard (e.g. boxes) [kg/month] ___________

Plastic [kg/month] ___________

Wood [kg/month] ___________

Polystyrene/Styrofoam [kg/month] ___________

Was any service or maintenance work done during the survey period, what kind of service work?

__ Engine Overhaul
__ Maintenance/service work on engine
__ Maintenance/service work on auxiliary systems
__ Other service work on facilities

Comments regarding maintenance/service work done e.g. on what equipment it was done, on how many engines and what was done ____

What is generally done with the different kinds of packaging material, check the most common option:

	Reuse at site	Reused by employees	Sent for recycling	Sent for incineration/disposal
Cardboard	__	__	__	__
Plastic	__	__	__	__
Wood	__	__	__	__
Polystyrene/ Styrofoam	__	__	__	__

C. Solid Waste – Hazardous

- Waste is considered hazardous if it has any of the following characteristics: ignitability, reactivity, toxicity or if it is corrosive. It is also considered hazardous if it has some other physical, chemical or biological characteristics that might cause it to be dangerous to human health or the environment.

- Pay attention to the units

Rags contaminated with: Oil, solvent or other hazardous product [kg/month] ___________

Empty cans, containers and drums [kg/month] ___________
Which used to contain hazardous materials like oil, solvents, paint etc.

Are some of the empty cans, containers or drums sent back to supplier to be reused, which kinds and what amount? ____

Lighting equipment and lamp ballasts [kg/month] ___________
E.g. fluorescent tubes and energy saving lamps

Batteries (e.g. nickel-cadmium and lead) and accumulators [kg/month] ___________

Other hazardous solid waste (excluding paper oil filters) [kg/month] ___________

What does the "other hazardous solid waste" consist of? _________________________________

Some additional questions regarding liquid waste: How big amounts of the below substances were disposed from the power plant site for treatment at contractor facilities during year 2015?

Sludge (oil) [m^3] ___________

Oily water [m^3] ___________

Used lube oil [m^3] ___________

Component washing solvents [L] ___________

Cutting oil (if collected separately) [L] ___________

Rejected closed circuit cooling water [m^3] ___________

If the oily water is not processed at site describe what is done with it _______________________

D. Electronic waste

Electronic waste (excluding spare parts) [kg/month] ___________
Computers, printers, heaters, kitchen equipment etc.

What does the electronic waste consist of? ____

E. Other questions

How big an area [m^2] is required for storing solid non-hazardous waste (excluding possible non-hazardous ashes)? __________

How big an area [m^2] is required for storing solid hazardous waste (excluding possible hazardous ashes)? __________

Were there any extraordinary events during the survey period which might have had considerable impact on the data? ____

F. Equipment specific questions

- When it is asked how often a filter or element is exchanged it is referred to all the engines or the auxiliary equipment in question. This means that when answering a question about how often e.g. a gas filter is exchanged think of how often it happens that a filter is exchanged on any of the engines.

F.1 - 32 HFO

If the most common engine type is 32 HFO engine, how often does it happen that a fuel oil filters on an engine is exchanged? [times/year] __________

Estimated weight of a used filter? [kg] __________

F.2 – Gaseous fuel

Filter location __ At engine __ At gas module

How often does it happen that a gas filter is changed? [times/year] __________

Estimated weight of a used filter [kg] __________

Gas pressure reduction station __ Yes __ No

Are the filters from the gas pressure reduction station disposed of together with waste from the power plant __ Yes __ No

How often does it happen that a filter in it is exchanged? [times/year] _________

Estimate the weight of a used filter [kg] __________

F.3 – SCR (Selective catalytic reduction)

Have any SCR elements been replaced, if so how many and after how many running hours?

____

What is done with the used SCR elements? ______________________________

Reagent used for the SCR __ Ammonia __ Urea

How is the reagent delivered? __ Tanks/bulk __ Ready-made liquid

__ Bags (urea) __ Big bags (urea)

Does the reagent give rise to packaging waste? __ No

__ Yes, amount [kg/month] ____

F.4 – Oxicat (Oxidation catalyst)

Have any oxicat elements been replaced, if so how many and after how many running hours? ____

What is done with the used oxicat elements? ________________________________

F.5 – Incinerator

What waste fractions are burnt in the incinerator? ___________________________

Ash amount generated by the incinerator [kg/month] ___________

Is the ash defined as hazardous waste? __ Yes __ No

What is done with the ash from the incinerator? ______________________________